FDOT TRANSPORTATION SYMPOSIUM 2019

Using Aerial Remote Sensing Methods to Enhance Transportation Planning

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Secretary's – Keynote charge

- Establish healthy partnerships.
- Provide the tools needed.
- Grab the vision.
- Do you have the "fire in the belly"?
- Streamline how projects are delivered.
- How can we improve ?

Project Description

Aerial Imagery Collection and Mapping for :

US 27 from the intersection of US 27 and SR 826 in Miami-Dade County to the intersection of US 27 and Florida Turnpike in Lake County, Florida. SR 70 from I-75 (Manatee County) to I-95 (St. Lucie County), Florida

Scope of Services (SOS) :
The aerial imagery collected for this project will consist of digital photography and Light Detection and Ranging (LiDAR) in support of transportation planning along US Highway 27 and State Road 70 roadway corridors.

Purpose : To provide to the planners geospatial data from one source that is reliable, organized, accurate, and not from disparate sources. The process will utilize precise GNSS / INS adjustment with optimum ground control to speedily deliver the mapping products to transportation Planning and possibly the PD&E and Design process.

Project Area Of Interest (AOI)

- US Highway 27 corridor from intersection of US 27 and SR 826 in Miami-Dade County to the intersection of US 27 and Florida Turnpike in Lake County, Florida and consists of a swath 1800 feet wide and approximately 244 miles long, with an approximate area of 74.3 square miles.

- State Road 70 corridor from I-75 (Manatee County) to I-95 (St. Lucie County), Florida and consists of a swath 1800 feet wide and approximately 137 miles long, with an approximate area of 41.7 square miles.

Sensor Collect Summary

Photographic Imagery

Aerial photography acquisition will be conducted only on days when conditions are considered optimal for collection of imagery and sun angle is 30 degrees or greater from the horizon. The total exposure count is approximately 9,291 frames with a forward overlap of 80%.

LIDAR Imagery

The point cloud resolution from LIDAR mapping shall be **greater than or equal to 8 points per square meter** in unobstructed areas. LIDAR scans shall be calibrated /aligned together to form a consistent classified point cloud. The final cloud shall have two LIDAR point classes:

ASPRS Standard LIDAR Point Classes	
Classification Value	Meaning
1	Unclassified
2	Ground

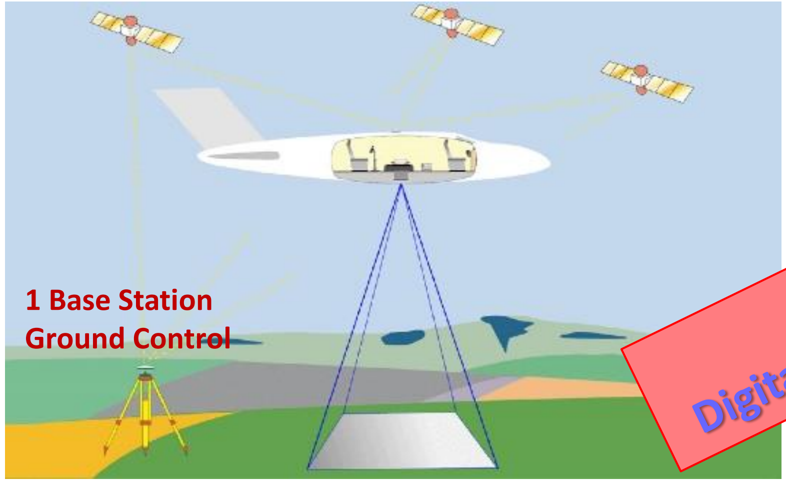
DRS in Photogrammetry/Lidar Mapping and the FPRN

Standard with GNSS + IMU Inpho 10.7.4

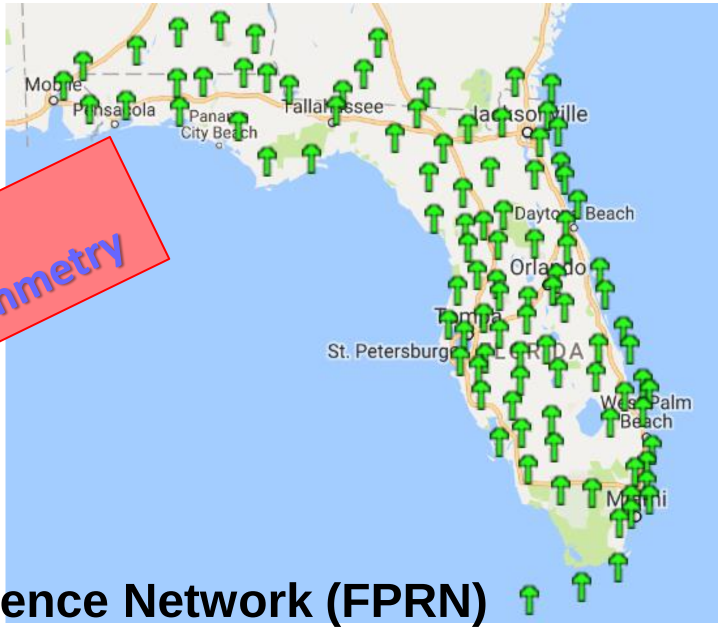
In theory control points are not needed when using GNSS/IMU data. In practice direct georeferencing (DRS) without aerial triangulation is not accurate enough.

The poor accuracy of exterior orientation parameters derived from direct georeferencing is a result of GNSS projection center coordinates not corrected for drifts and shifts. Aerial triangulation can help to refine those positions.

Just one ground control point is sufficient to determine the shift in GNSS/IMU measurements, to correct for the drift, requires at least one more control point.

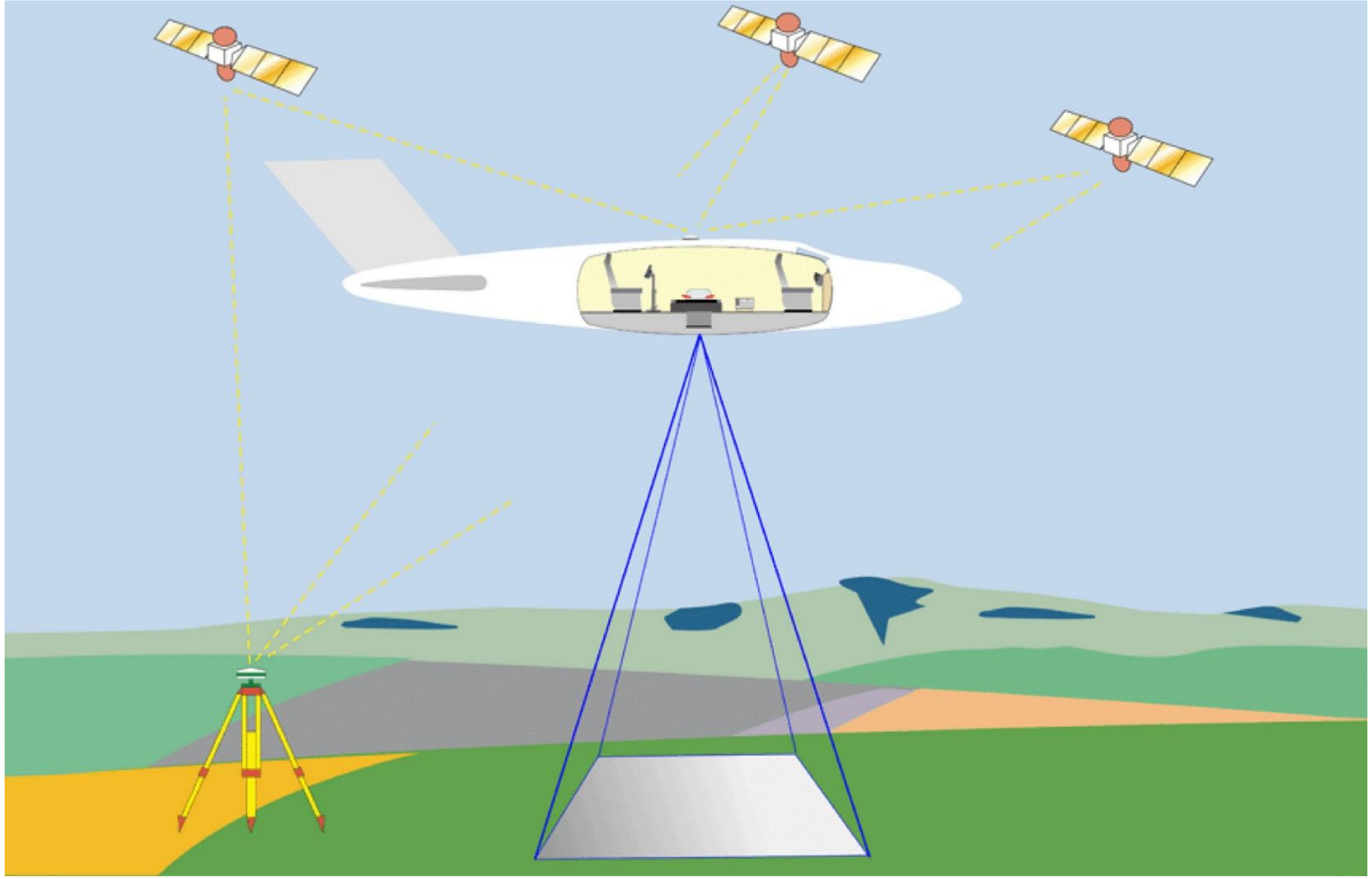


The Holy Grail of
Digital Aerial Photogrammetry



Florida Permanent Reference Network (FPRN)

Leica RCD30 Digital Direct Reference System (DRS)



QC Checks for DRS:

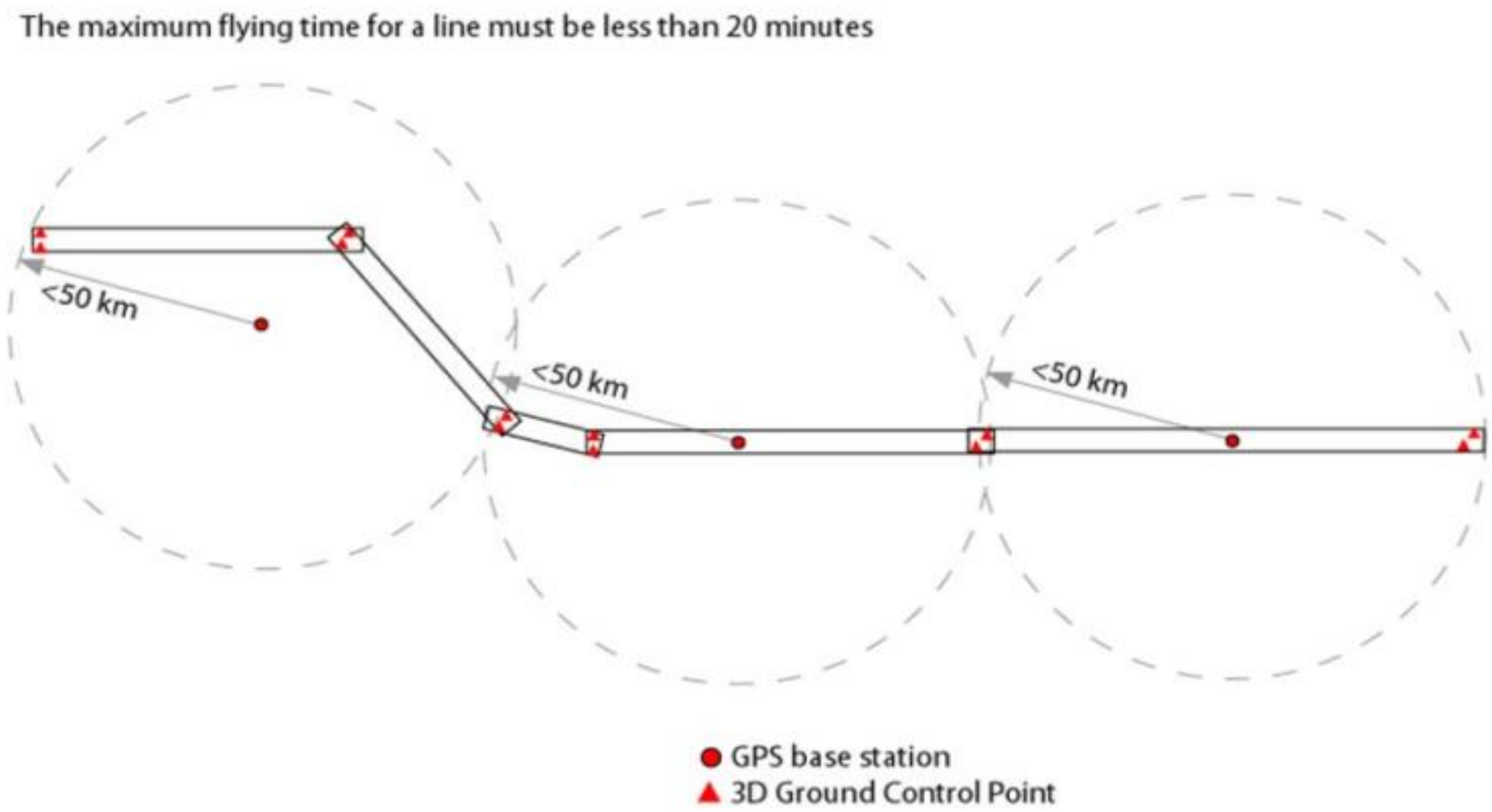
1. **Lever Arms Offsets**
2. **Boresight Calibration - 3 months**
3. **Consistent GEOID model**
4. **Base Station Antenna Offsets**
5. **Desired Coordinate Output. e.g. SPCS, LL**

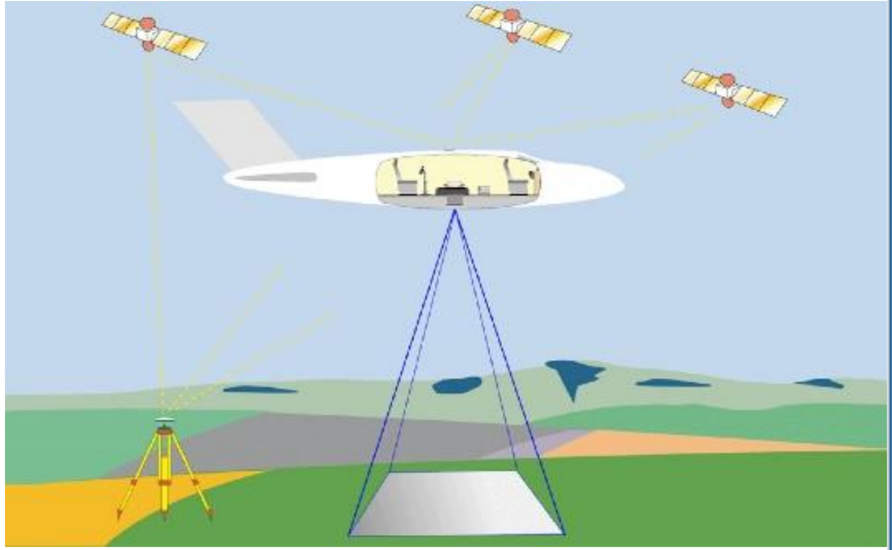
Leica DRS for Corridor Mapping

Corridor mapping

At each corner of a strip of the corridor two 3D-Ground Control Points should be placed such that it is covered by the current flight line and by the flight line next in sequence. An example is given in Figure 88 below.

Figure 88: Example Corridor Mapping



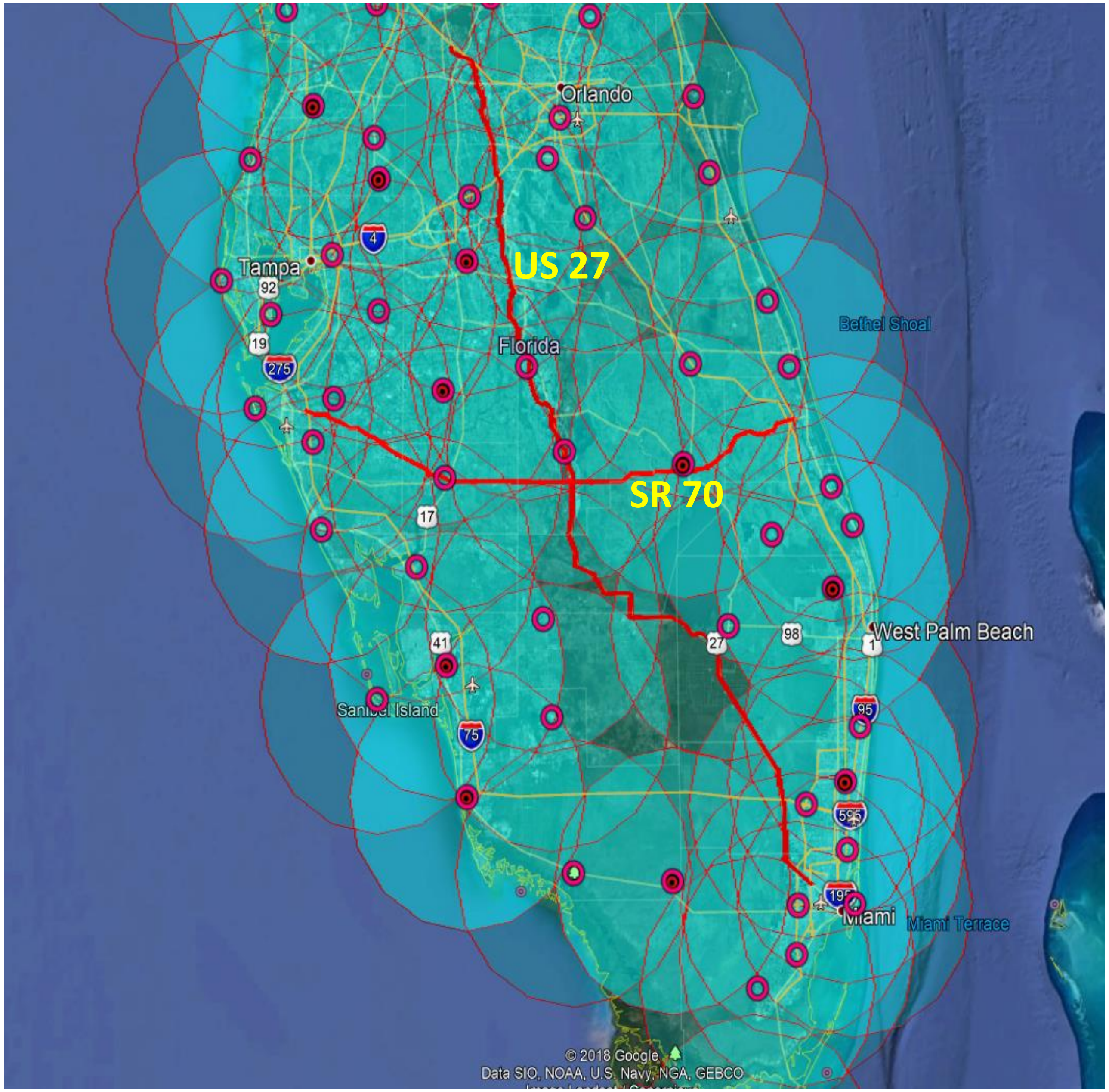


Leica RCD30 Aero-Triangulation Configurations

Project Data and Accuracy expectations

							Approximate Ground Control Points			
Project Site	Coverage Width	Approximate Photo Images	Photo Resolution	LIDAR Resolution	Corridor Miles	Flight Lines	Targeted	Image Identifiable	NSRS Vertical	Total Control Points
US27	1800'	5934	0.25'	≥ 8 points/meter²	244	105	23	109	24	156
SR70	1800'	3357	0.25'	≥ 8 points/meter²	137	70	25	57	14	96
Total		9291			381	175	48	166	38	252

FPRN GPS base-stations along US 27 / SR 70 corridor



	FPRN		BaseStations	
	Along SR 70	20	Along US 27	33
1	STPT		MTNT	
2	FLAI		HOME	
3	GSPS		RMND	
4	FRUT		FLMB	
5	ANDE		FLD6	
6	WACH		FLND	
7	RCDA		FTLD	
8	PNTA		BOCA	
9	LBLL	50 Km	LAUD	
10	FLLP		GLAD	
11	AVON		PBCH	53 Km
12	GLAD	60 Km	FLIT	
13	FLIT		MMO	
14	OKCB		LBLL	
15	FLFD		PNTA	65 Km
16	FLFR		RCDA	
17	STEW		OKCB	
18	FLHO		FLLP	
19	SBST		AVON	
20	FLGR		FLFD	65 Km
21			WACH	
22			AVON	
23			BRTW	
24			POLK	
25			FLCC	
26			ORL1	
27			ZEFR	
28			FLKS	
29			ORL1	
30			FLDC	
31			FLWD	
32			FLEU	
33			SNFD	52 Km

GNSS/INS –WPK to RPH

Comparing Attitude Solutions

To compare the photogrammetrically determined attitude to the attitude provided by the inertial navigation solution, some intermediate data processing was required. The inertial navigation solution reports roll, pitch and heading (RPH). The photogrammetric system uses omega-phi-kappa (WPK) angles. These two angular systems differ in several ways, summarized in Figure 6.

WPK angles describe the rotation from the ground to the aircraft, whereas RPH angles describe the rotation of the aircraft with respect to the ground. In the photogrammetric system, WPK are generally applied in that order, although PWK can also be used. In SPAN and Inertial Explorer, the order of rotations is RPH, which is about z, about x, and then about y.

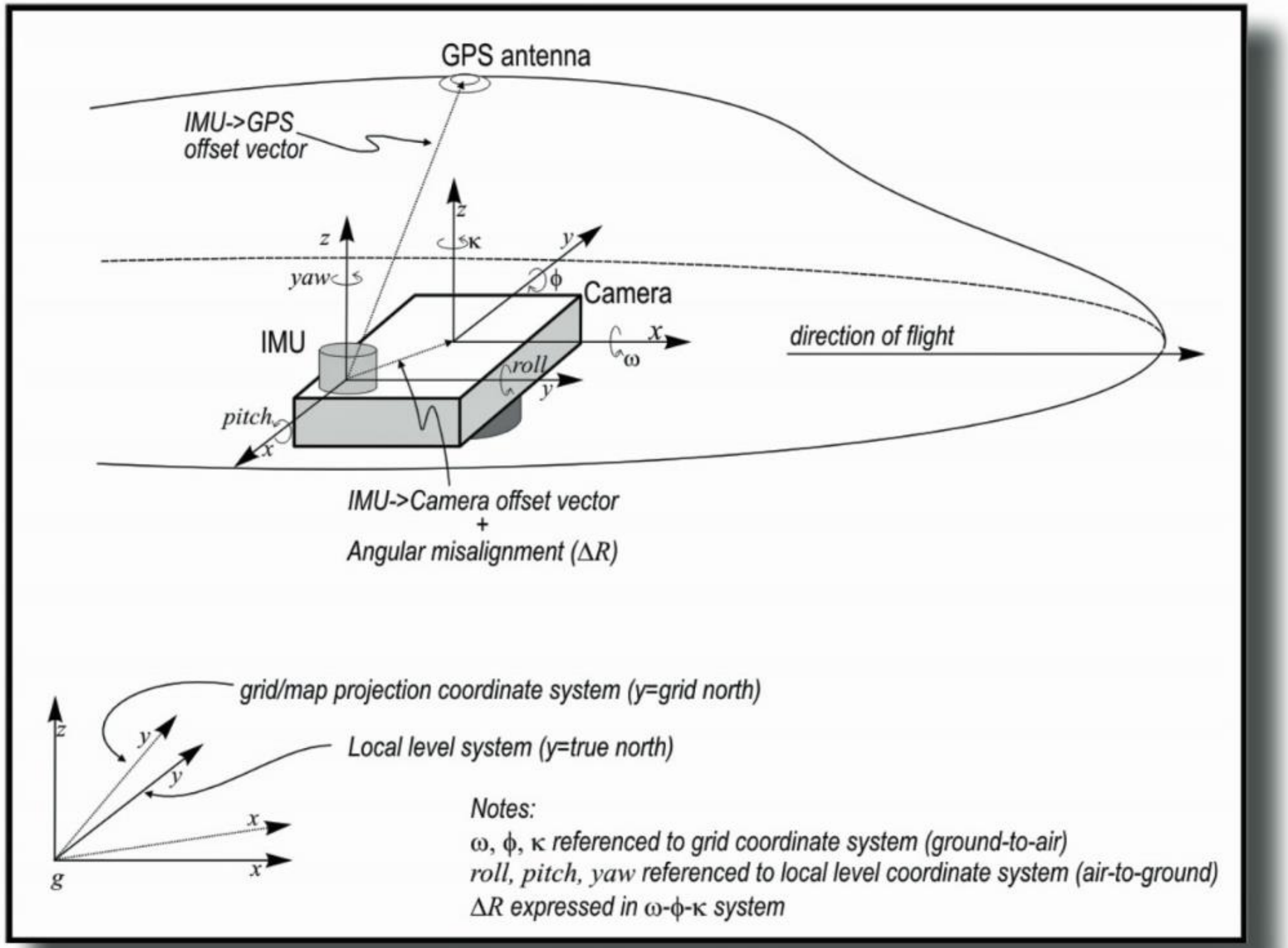


Figure 6: Relation of Omega-Phi-Kappa (WPK) to Roll-Pitch-Heading (RPH)

FDOT and FPRN desired Applanix processing mode

IN-Fusion SmartBase

IN-Fusion SmartBase is a feature in the POSPac MMS software that addresses the limitations of traditional integration approaches using high-accuracy carrier phase differential GNSS for mobile mapping. SmartBase processing is optimized for large changes in altitude by the rover and is extended to work with reference stations separated by very large distances. It uses the tightly-integrated Applanix IN-Fusion technology to provide a robust and highly accurate aided inertial position and orientation solution using a network of reference stations. The Applanix SmartBase engine processes the observables (phase and pseudorange to each tracked satellite) from a minimum of four to a maximum of 50 continuously-operating GNSS reference stations surrounding the trajectory. The computed ionospheric, tropospheric, satellite clock, and orbital errors at the reference stations are used to correct for the errors at the location of the remote receiver. IN-Fusion includes Inertially-Aided Kinematic Ambiguity Resolution (IAKAR) that provides fast fixed-integer ambiguity recovery following GNSS signal outages. For more information on SmartBase processing, see Technologies and Features and Processing Techniques.

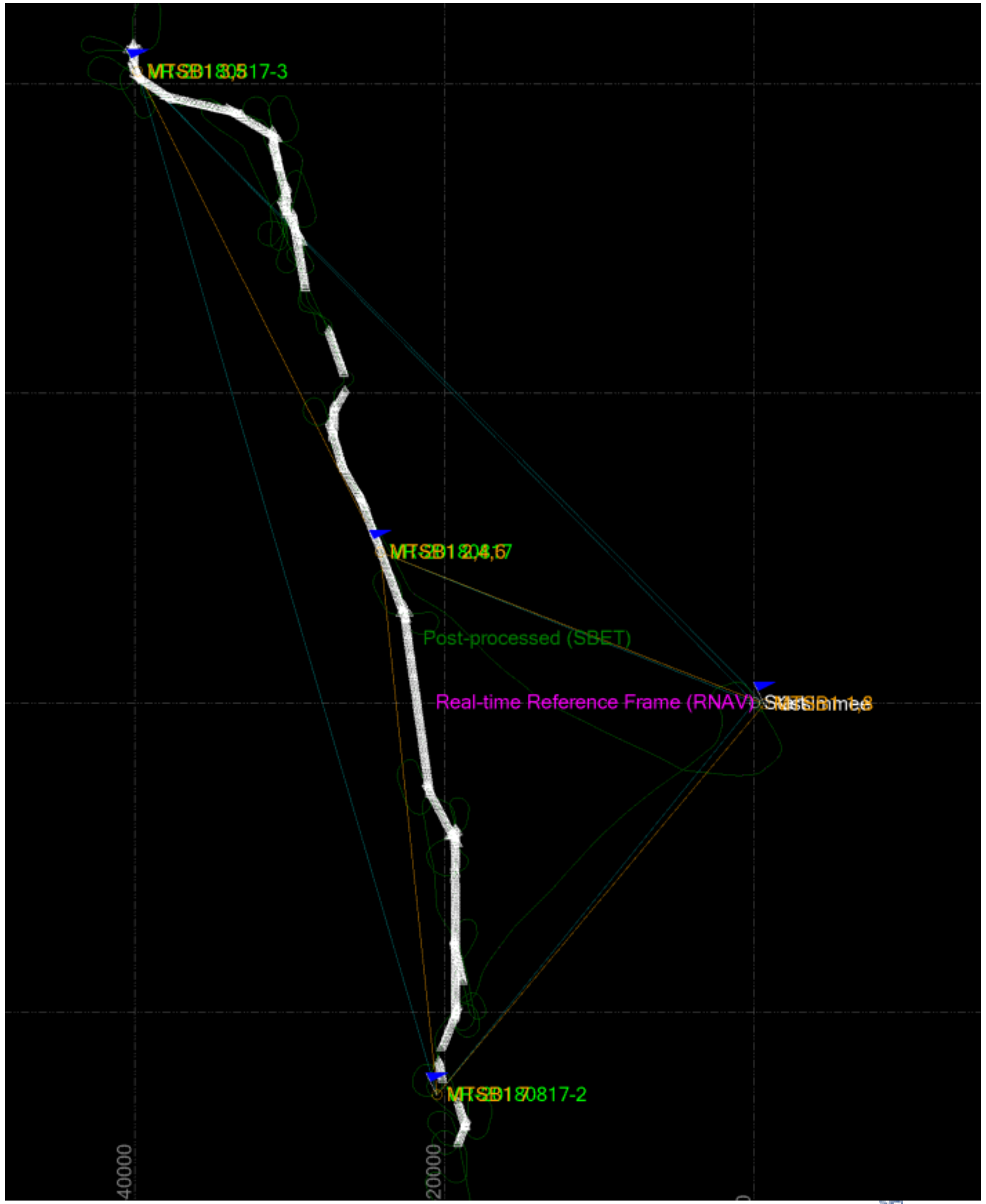
SBET (Smoothed Best Estimate of Trajectory)

GNSS-Inertial Processor

The GNSS-Inertial processor is used to compute a Smoothed Best Estimate of Trajectory (SBET) using the raw inertial, GNSS satellites, and base station data. There are several GNSS-Inertial processing modes available:

Processing mode	Description
IN-Fusion SmartBase	Tightly Coupled SmartBase KAR
IN-Fusion Single Base	Tightly Coupled Single Base KAR
IN-Fusion PP-RTX	Tightly Coupled PP-RTX
IN-Fusion PPP (IAPPP)	Tightly Coupled PPP
IN-Fusion Autonomous	Tightly Coupled CA Tightly Coupled Code DGPS
IN-Fusion GNSS Nav Single Base	Loosely Coupled Differential GNSS
IN-Fusion GNSS Nav SmartBase	Loosely Coupled Differential GNSS
IN-Fusion GNSS Nav PP-RTX	Loosely Coupled PP-RTX
POSGNSS KAR	Loosely Coupled Differential GNSS
POSGNSS PPP	Loosely Coupled PPP
Primary Trimble RTX Nav	Loosely Coupled Primary Trimble RTX
Primary OmniSTAR Nav	Loosely Coupled Primary OmniSTAR
Primary Marinestar Nav	Loosely Coupled Primary Marinestar
Primary GNSS Nav	Loosely Coupled Primary GNSS (AV data only)
Auxiliary GNSS Nav	Loosely Coupled Auxiliary GNSS

 POSPAC MMS GNSS-INERTIAL



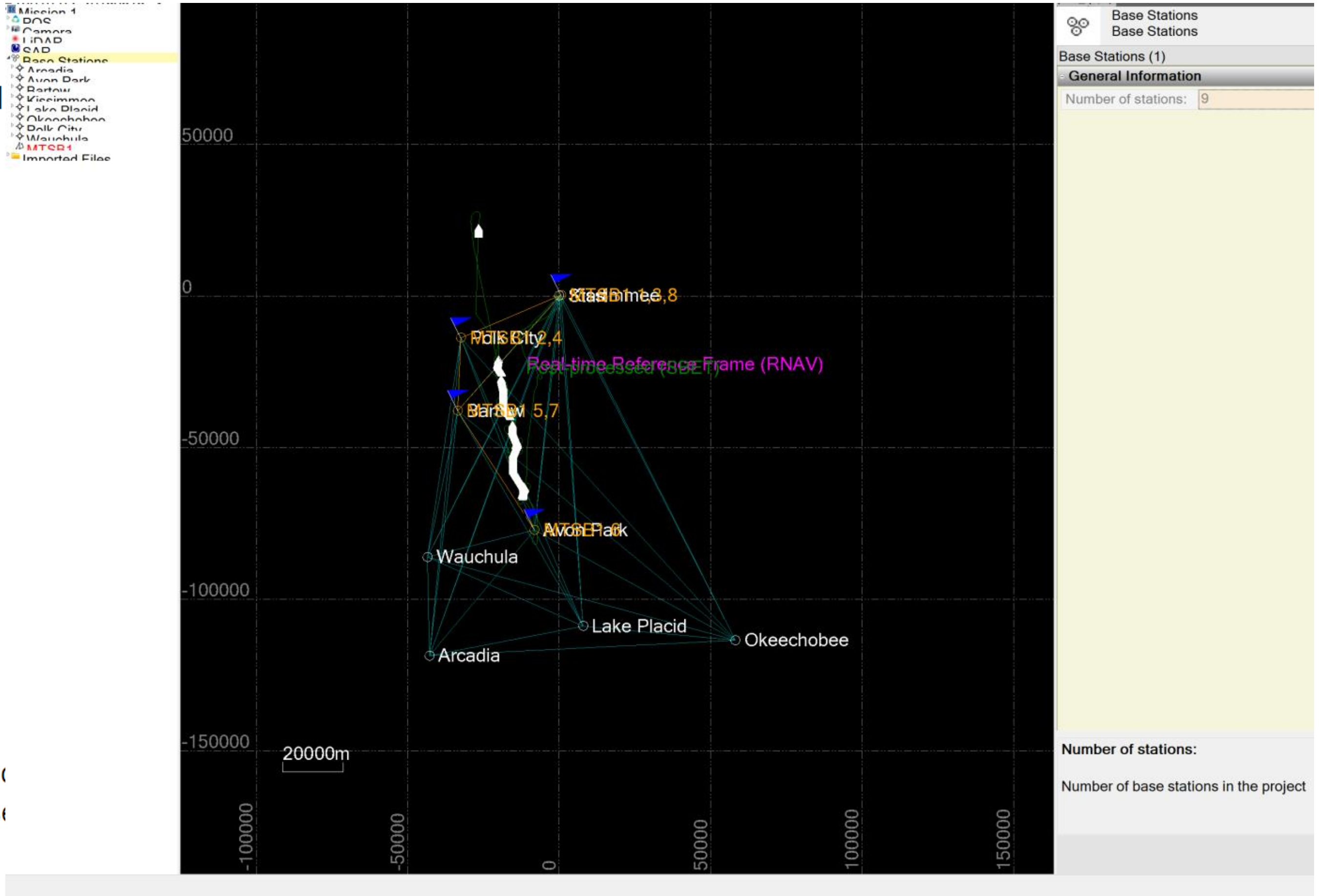
Multi Single Base Object (MSB) by Applanix

Applanix IN-Fusion Multi-Single-Base (MSB) processing

In-Fusion Multi-Single-Base (MSB) Processing is designed for customers who need the highest level of Differential GNSS position accuracy and who perform long, linear projects such as power line corridors, long highways, or stretches of coastline where a network of GNSS base stations is either unavailable or the geometry of the network is weak and an Applanix SmartBase™ solution is not viable. It allows for the establishment of base stations along the full length of the survey path and makes optimal use of the nearest base station at all times along that path.

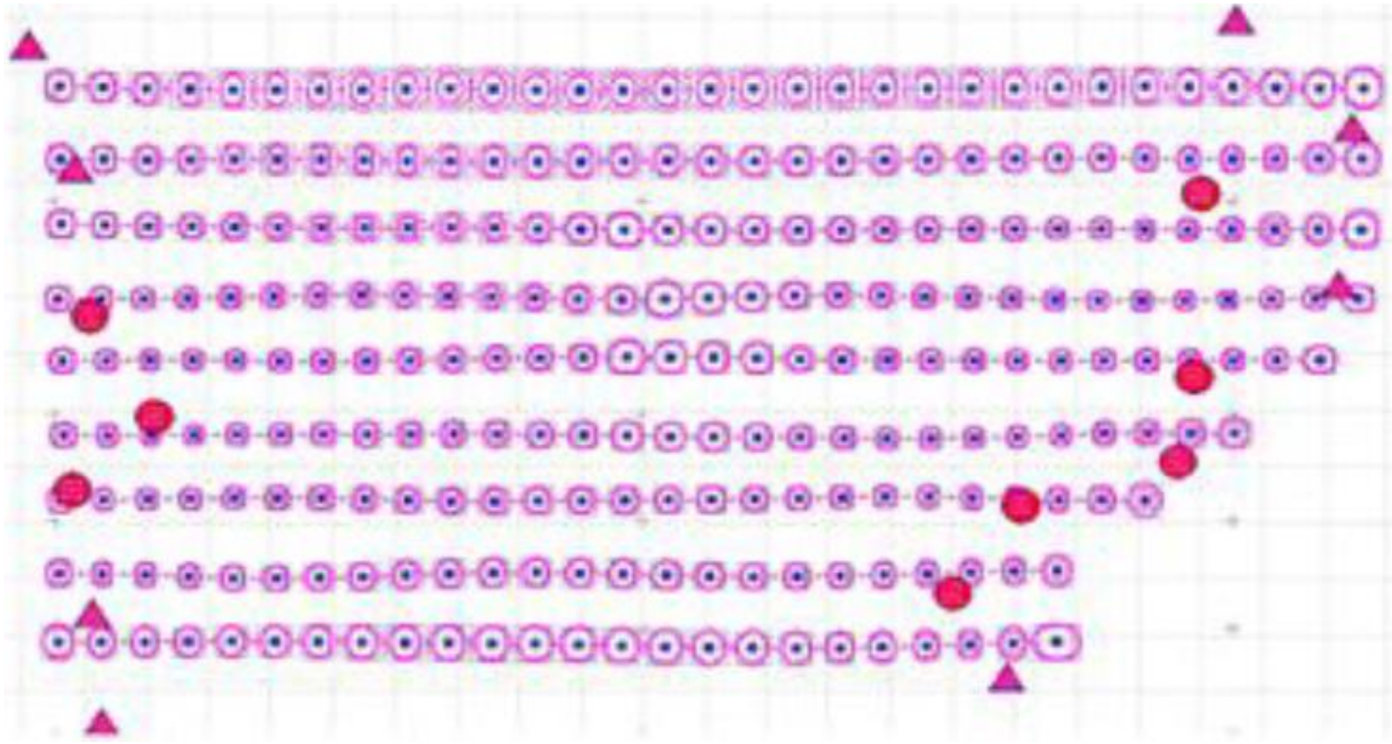
MSB process is initiated by selecting multiple reference stations and running the “Create MultiSingleBase” command. The MSB process runs through the rover data and at every epoch identifies the best base station among the ones selected for the GNSS-Inertial processor to use at that epoch. Much of the processing (Decoding and Repairing GNSS Data, Checking GNSS Observables Quality) are ran in parallel, which greatly reduces the processing time. The GNSS-Inertial solution generated with Multi-Single-Base is the combination of segments of single baseline processing solutions. Although MSB can process with any inter-station distance, the maximum baseline length of each single baseline processing segment should be within 20 km in order to obtain the best performance.

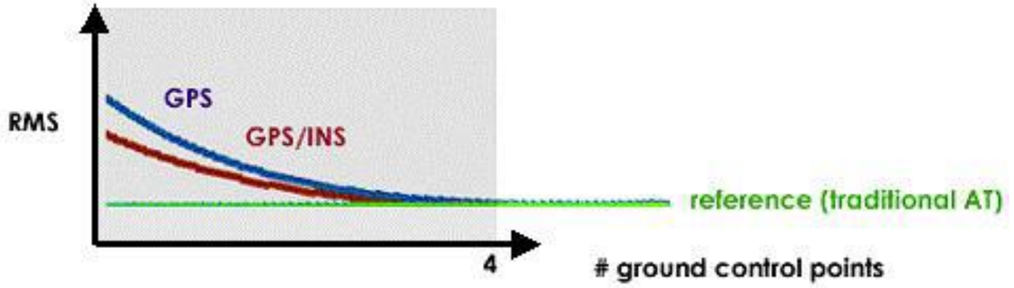
For the consistency of the MSB solution, it is important that good quality reference station data anc accurate coordinates be used. If the stations are downloaded from GNSS online services, SmartBas Quality Check can be used to estimate consistent coordinates for MSB processing.



GNSS/INS – Good Drift and Shift Correction

Good and reliable computation of exterior orientation parameters!





"From a photogrammetric point of view, there is a great advantage in the stability of a system with a minimum of moving parts"

ASPRS Manual of Photogrammetry- Sixth Edition Sec 14.2.2

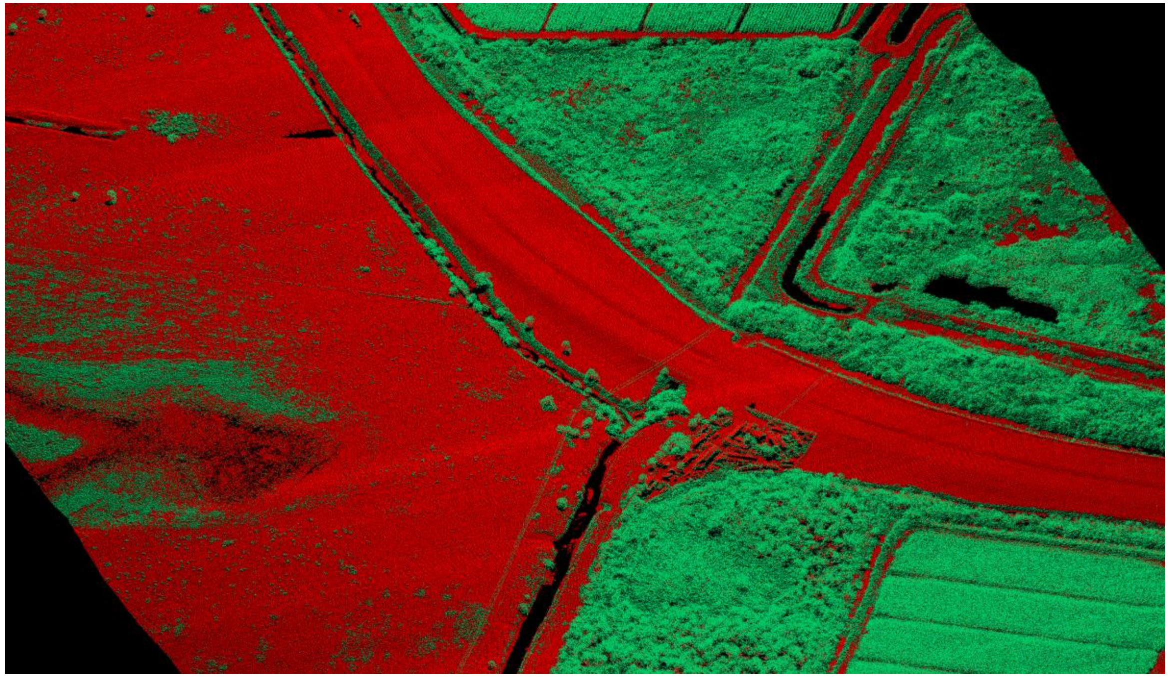
Planning US 27/ SR 70 Collect Aerial Photography & Lidar

- Aerial Photography RGBN – 7 TB raw collect

Aerial Photography

The Ground Sample Distance (GSD) of the source photographic imagery will be **0.25 feet**. The Digital aerial photography will have a project horizontal accuracy sufficient to provide stereo compilation accuracies of **0.25 feet RMSE horizontally** and **0.5 feet RMSE vertically**,

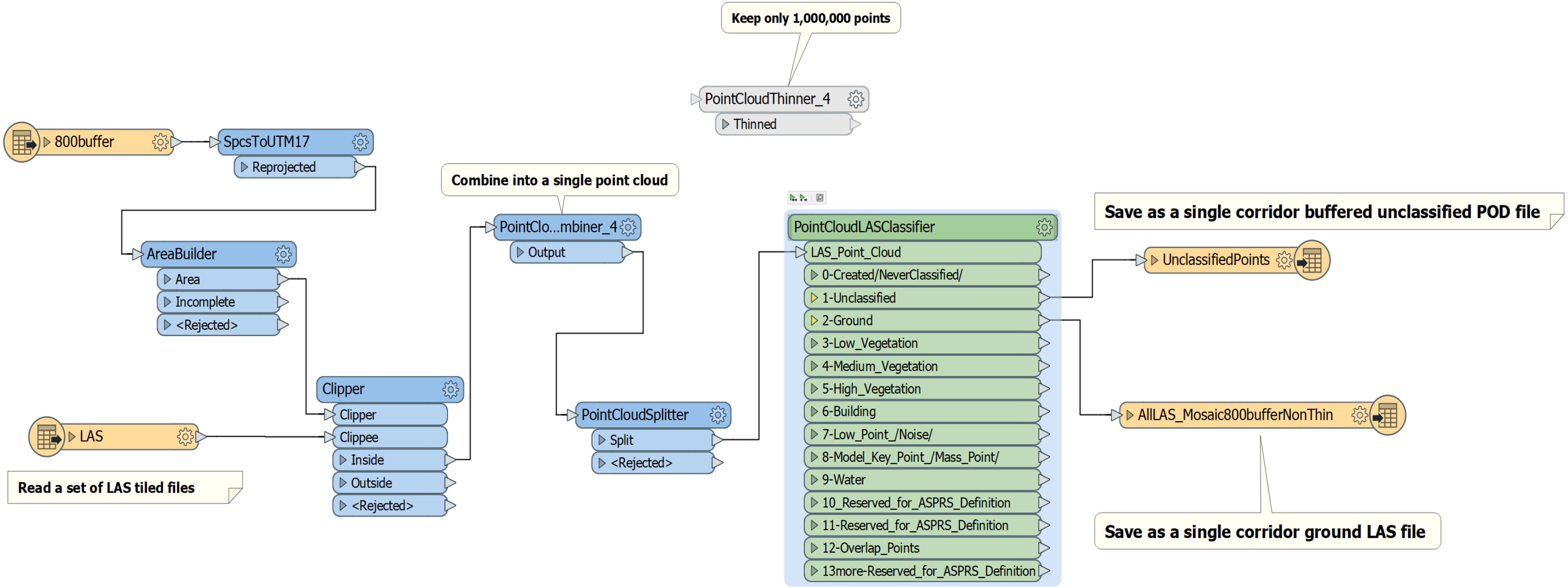
- Aerial Lidar – 2 TB raw collect



Lidar:

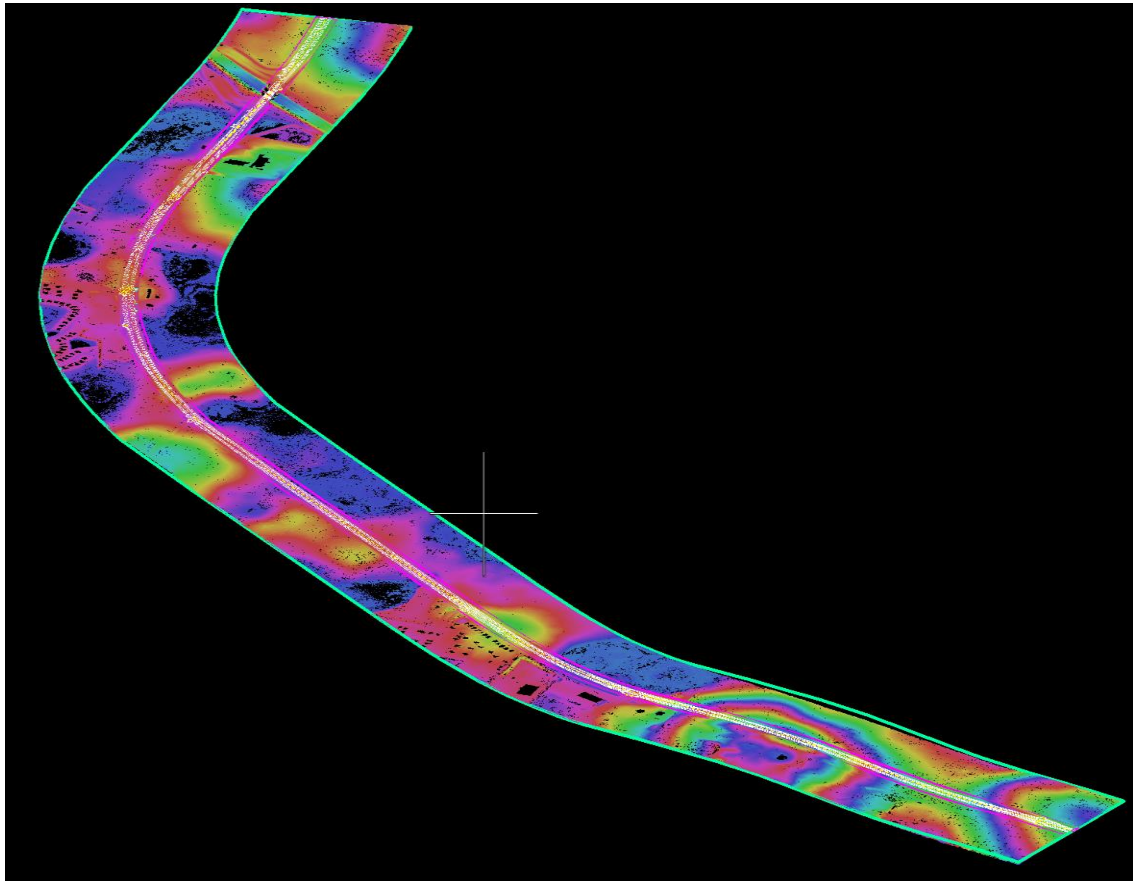
The aerial LIDAR has a project horizontal accuracy of **0.5 feet RMSE** and a vertical accuracy of and **0.25 feet RMSE in Non-Vegetated Areas (NVA)**

Point Cloud combining along US 27 corridor

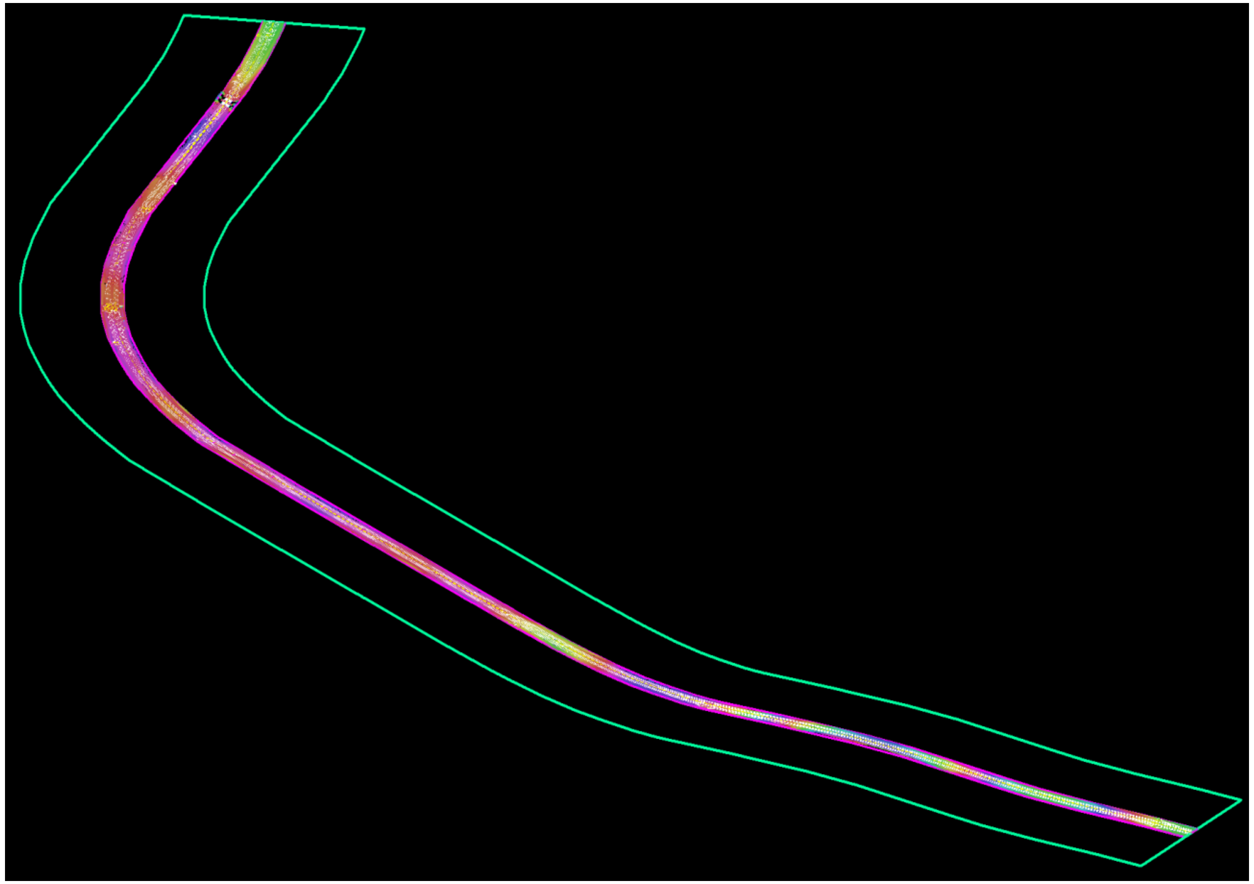


Ground Classified lidar data - e.g. US 27

- 1600 ft Buffer Mainly Soft Surface



- 200 ft Buffer RoW to RoW Mainly Hard



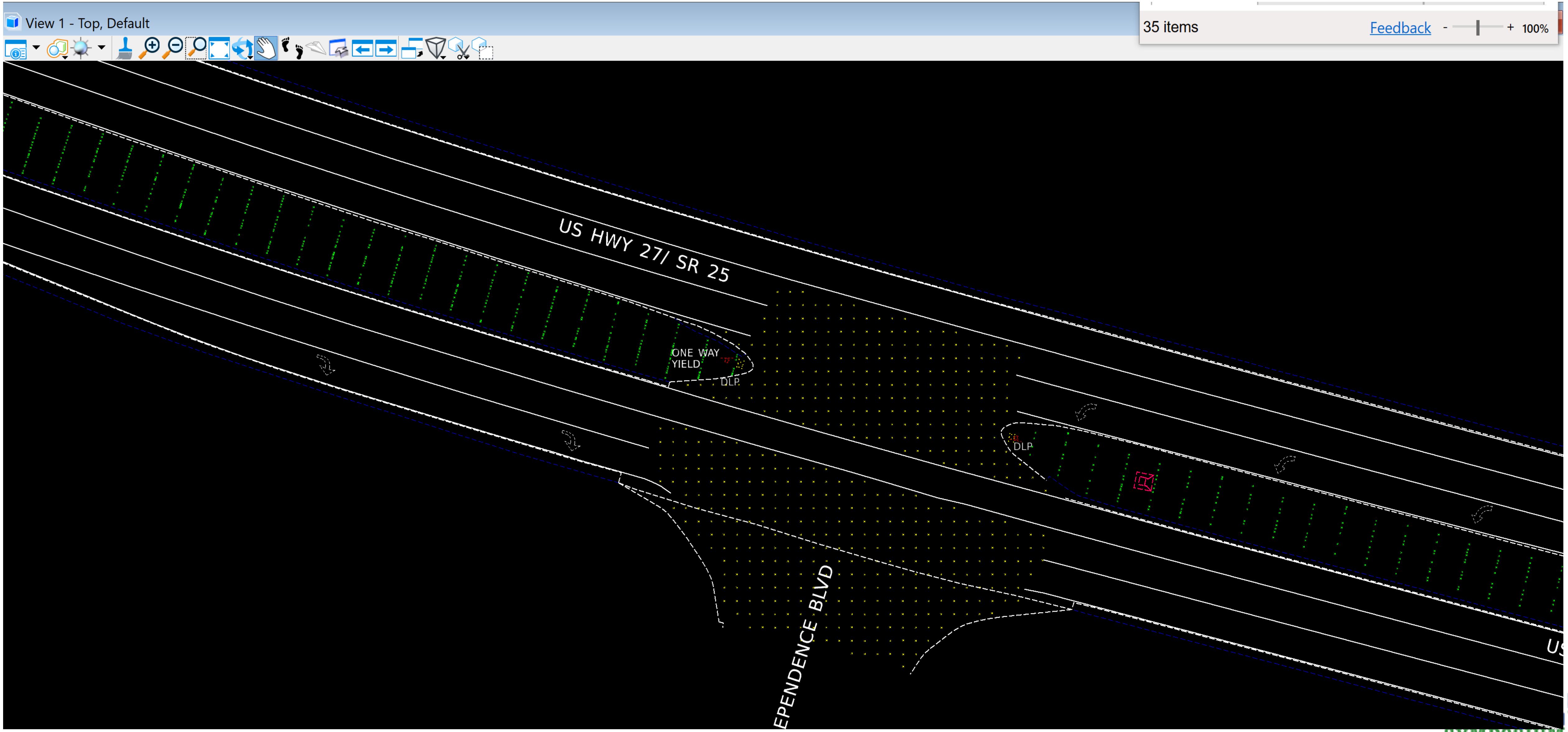
TML Design Collect compared to Planning Collect

PROJECT APPROACH & EXECUTION

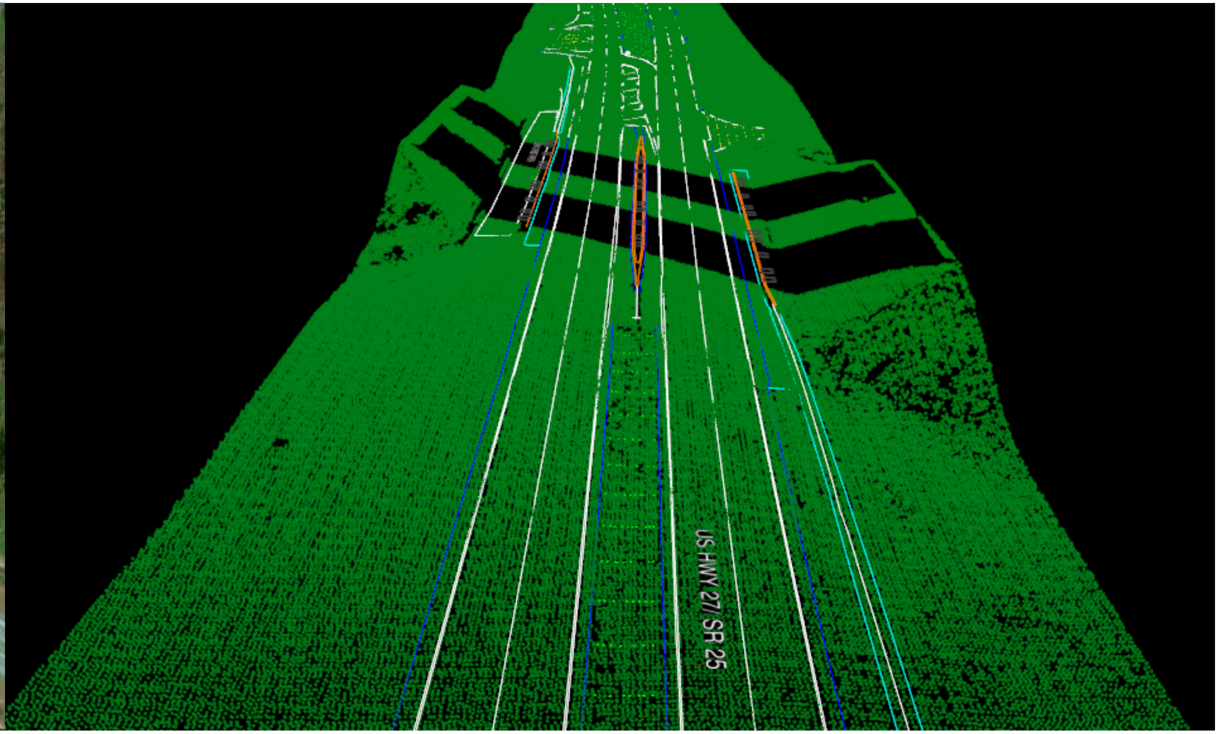
Execution of the Resurfacing and Safety Upgrades – SR25 (US27) from approximate MP 23.818 (O'Brien Rd.) to approximate MP 32.077 (South of CR 48) 34 lane miles while collecting Nikon D810 imagery simultaneously. Two Leica base stations were running during collection to help trajectory post processing. Below are set parameters used during the scanning of the project.

Survey/Collection Date (s): November 19, 2016
Sensor: VMX-450
Platform: Dodge Ram ProMaster
Collection Software: RiACQUIRE MLS
Number of Drive/Scan Lines: 4 **(APPENDIX B)**
Number of Exposures: 16,144
Speed: 55mph
Point Density: 350 points per meter average
Scan Rate: 30m 30kmh 550kHz 200lps

TML data used to verify US 27 Lidar and Photo collect



TML Design MAP referenced to US 27 Planning Collect



FDOT
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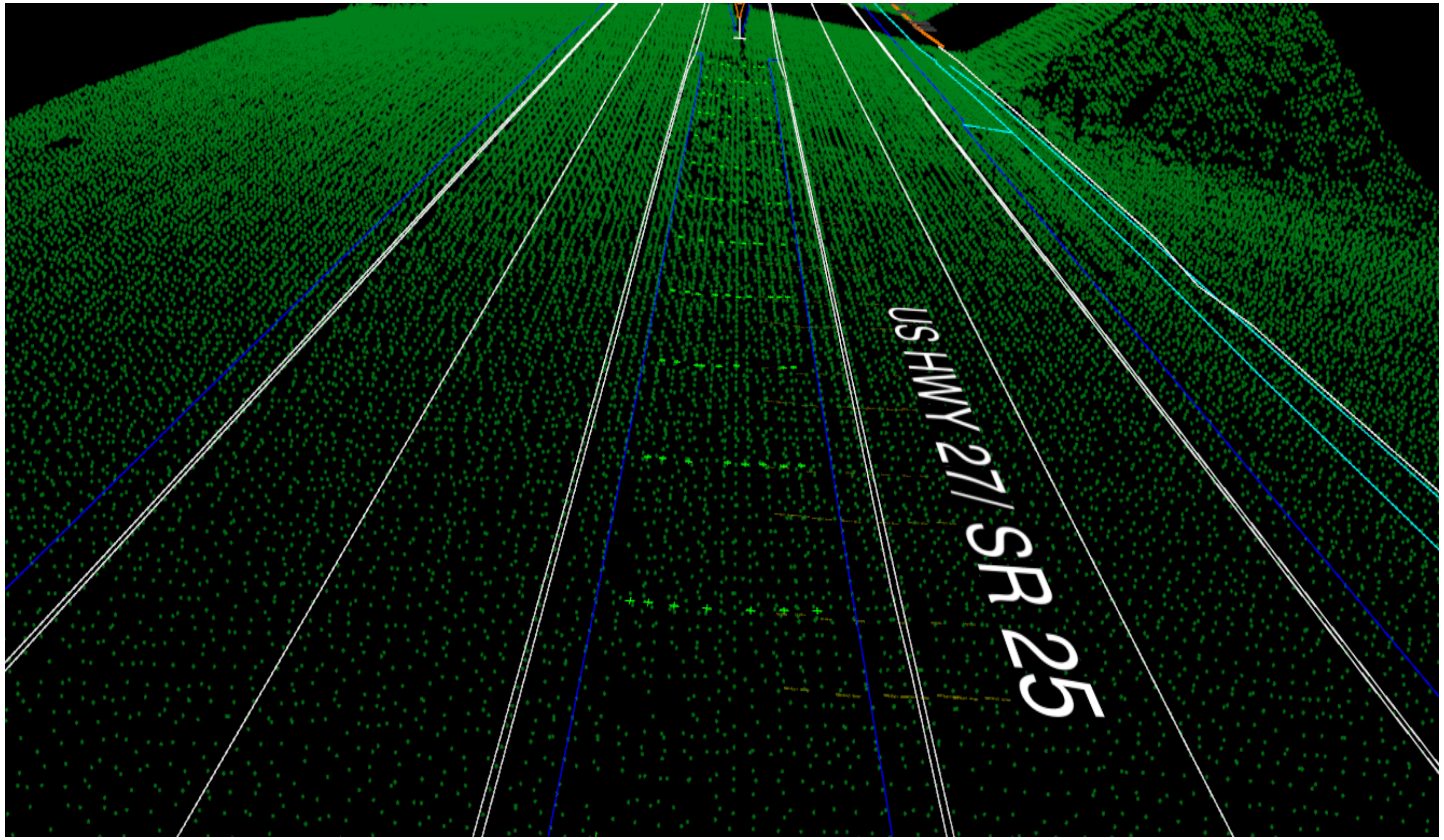
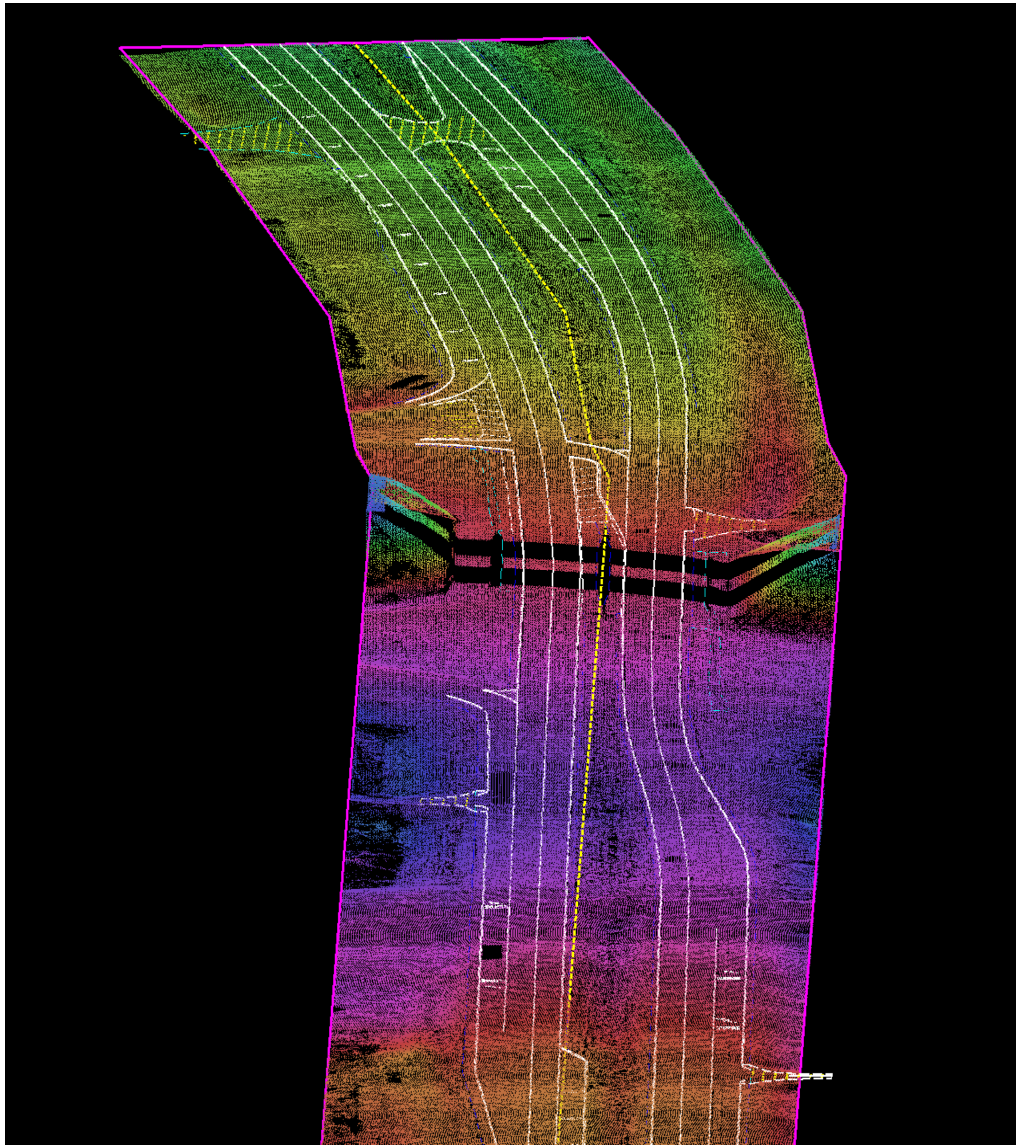
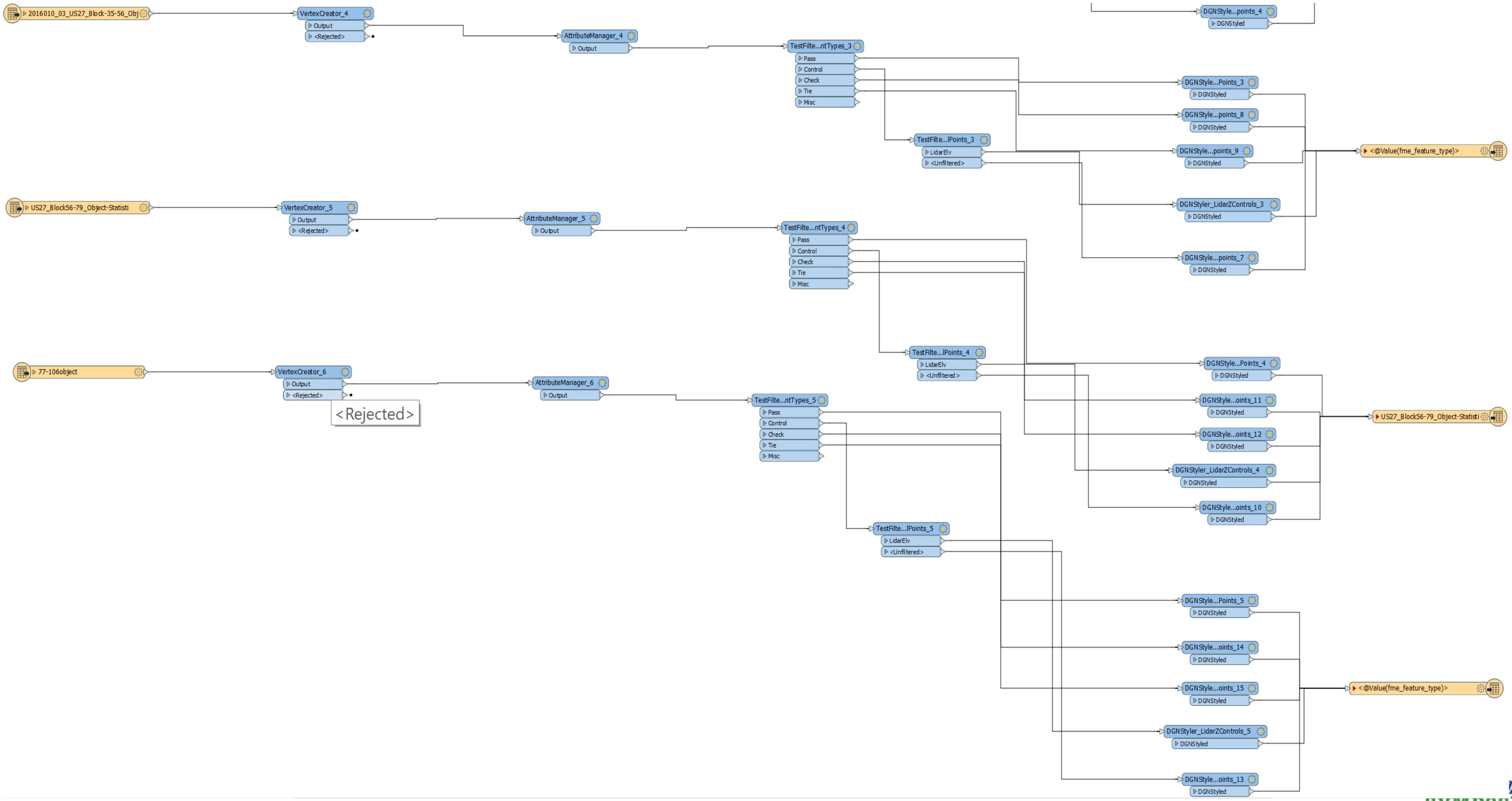
Hard surface match on US 27





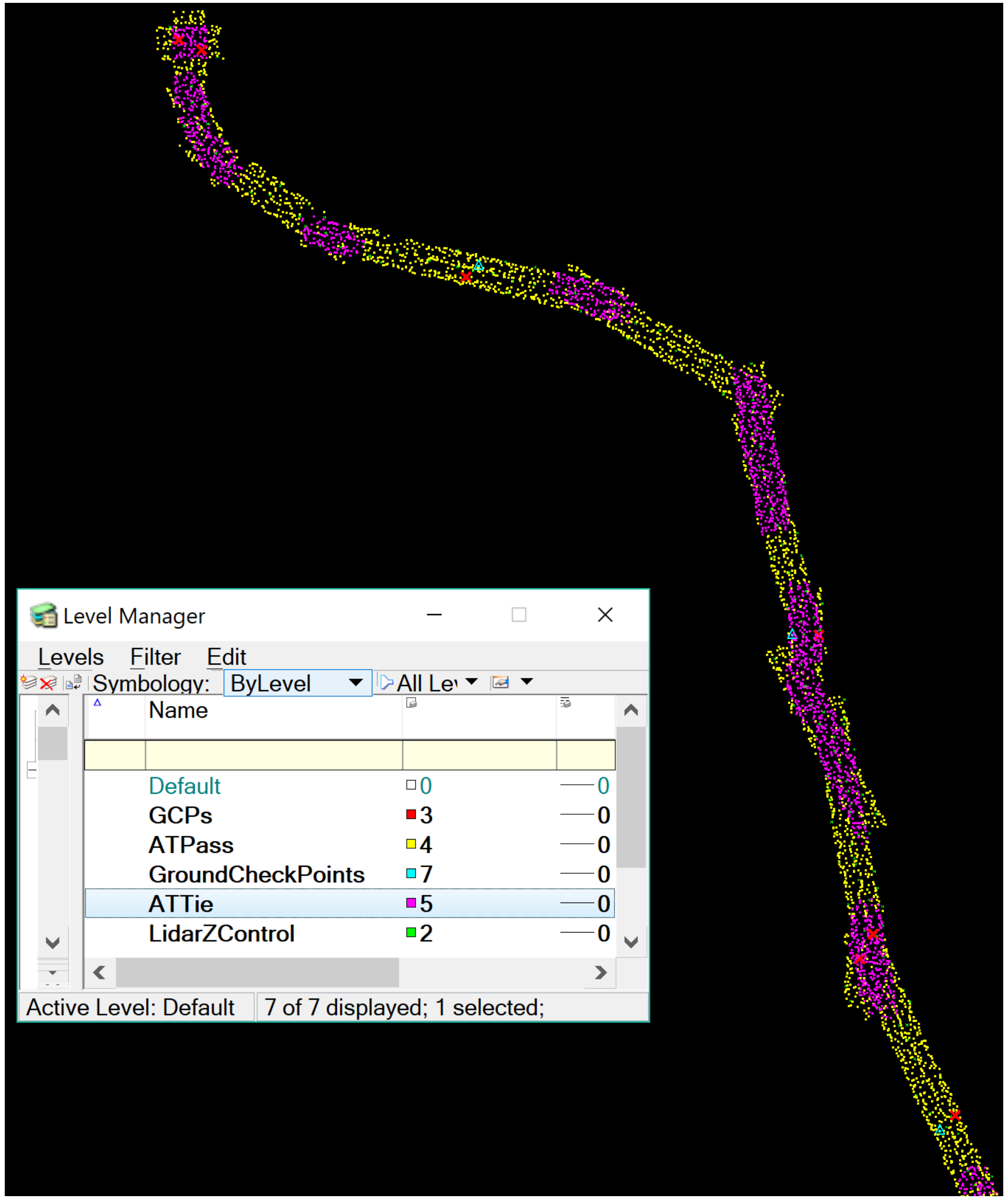
FDOT TRANSPORTATION SYMPOSIUM

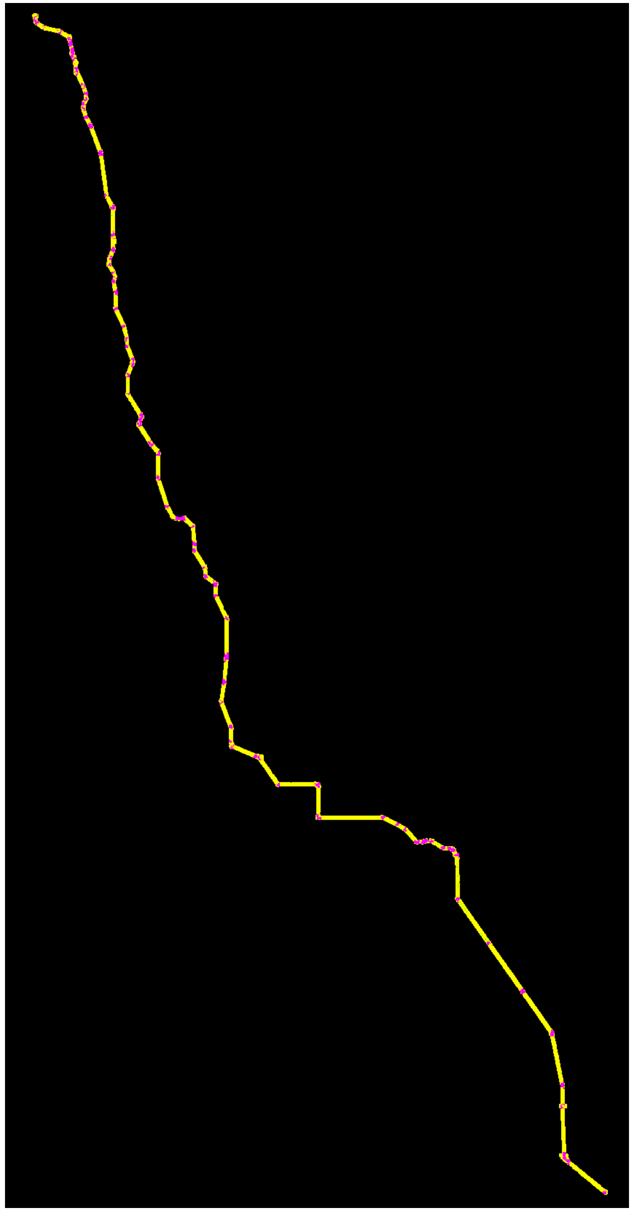
Manipulate the AT reports to review graphically



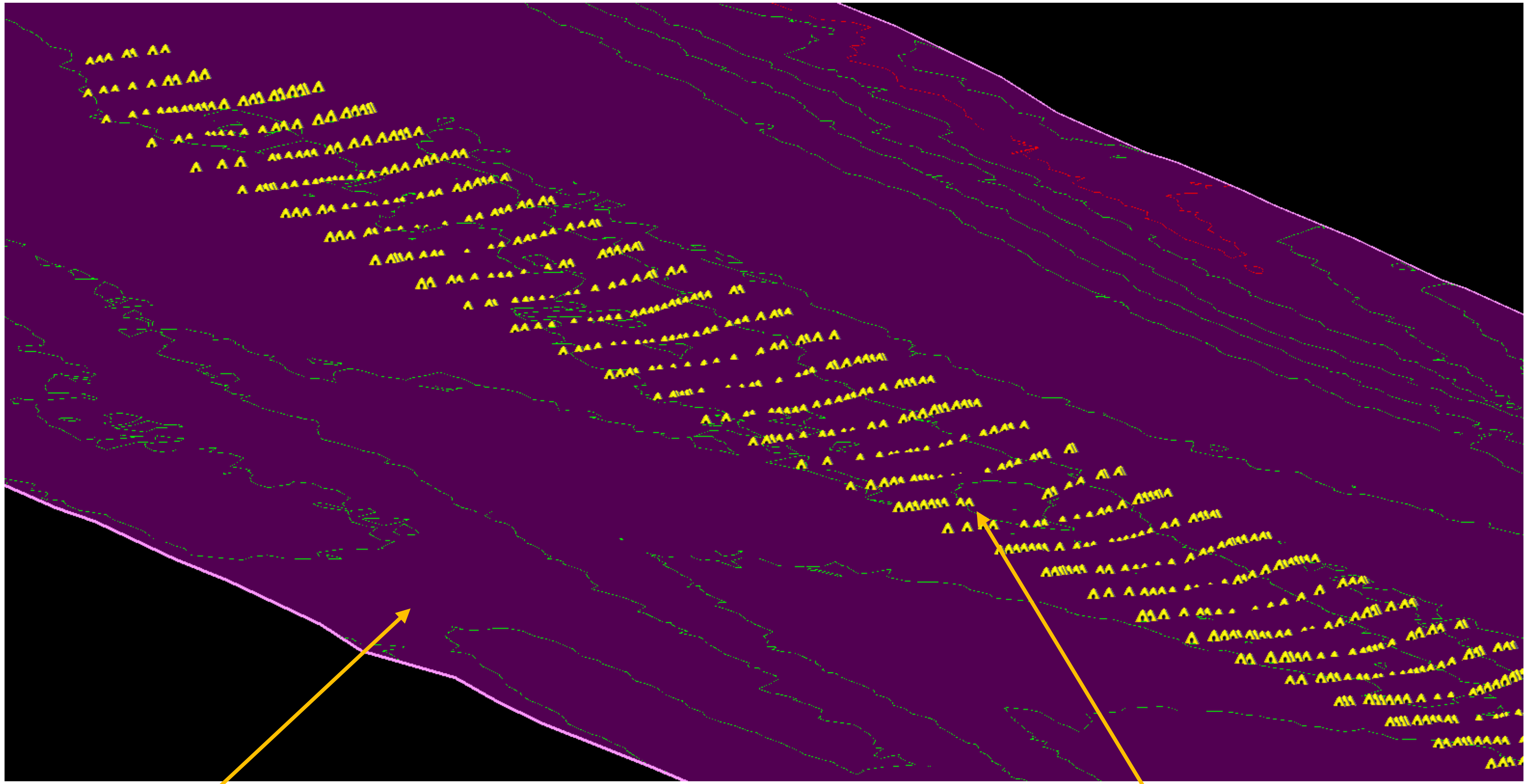
ATION SYMPOSIUM

AT Blocks mapped for inspection





TML Soft Points & Lidar TIN comparison



Lidar TIN

Soft Points

Points PASS the 95% confidence test based on 1.96 Chi Square Value.

User defined Tolerance = 1

==

39.0% of points are between Half Tolerance and Tolerance

26.4% of the points are greater than Tolerance

-2 is the maximum difference BELOW

1 is the maximum difference ABOVE

5296 Total number of points

1393 Points are below the TIN Surface

4 Points are above the TIN Surface

3899 Points are equal to the TIN Surface

SR70 Orthoimagery Creation

SOURCE IMAGERY SPECIFICATIONS

FLIGHT ALTITUDE- 1800ft AGL

CORRIDOR SPECIFICATIONS- 1800ft wide, 137 miles long

DATES OF FLIGHT- Aug 19 – Sep 26, 2018

FLIGHTLINES- 70

TOTAL IMAGES- 3371

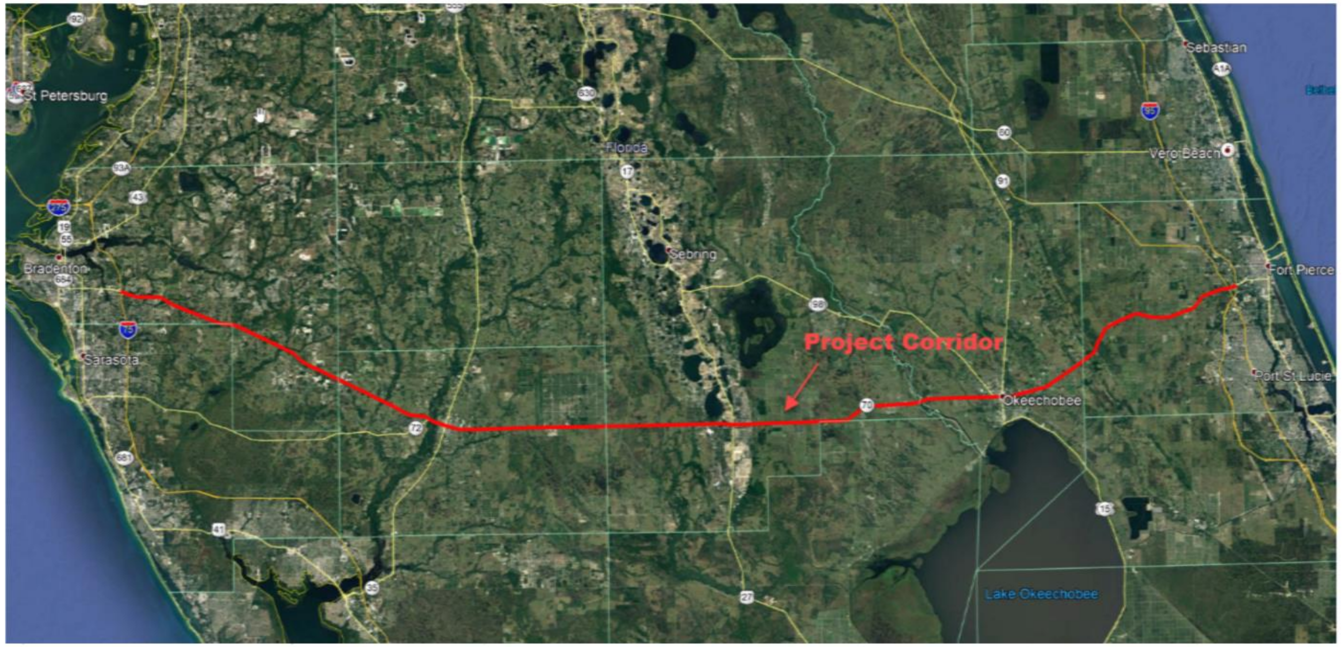
CAMERA- Leica RCD 30

FORWARD OVERLAP- 80%

GSD- .25ft

IMAGE FORMAT- RGBI TIFF

ABGPS/IMU- Directly referenced to FPRN



Leica RCD30 Medium Format RGBN Camera

Characteristics of Data Acquisition

CCD Size (80MP – Camera Head CH81/82)
10320 x 7752 pixels
Pixel Size
5.2 µm
Dynamic Range of CCD
73 dB

CCD Size (60MP – Camera Head CH61/62)
8956 x 6708 pixels
Pixel Size
6 µm
Dynamic Range of CCD
73 dB

Resolution A/D Converter
14-bit

Data Channel
16-bit lossless

Maximum Frame Rate
60MP: 1.00 sec
80MP: 1.25 sec
Penta: 1.80 sec

Motion Compensation
Mechanical forward and lateral motion compensation along two axis

Spectral Range

Camera Head CH81/61	RGB
Camera Head CH82/62	RGB and NIR, coregistered
NIR Range	780 – 880 nm

Optics

Lenses
Leica NAG-D 50 mm
Leica NAT-D 80 mm
Leica SAT-D 150 mm
Ruggedized and temperature compensated for high accuracy performance between – 10°C and +30°C

Shutter
Central shutter, user replaceable
Life >200'000 frames

Aperture
4, 5.6, 8, 11 for NAG-D 50 mm
2.8, 4, 5.6, 8 for NAT-D 80 mm
4, 5.6, 8, 11 for SAT-D 150 mm
Automatically controlled aperture

Lens Mount
Easy to use bayonet connection
Automated electrical connection
Stabilized connection mechanics

Physical

Camera Head CH8x/CH6x

Weight	w/o lens 3.1 kg
	with NAG-D 50 mm 3.9 kg
	with NAT-D 80 mm 3.6 kg
	with SAT-D 150 mm 3.9 kg
Height	w/o lens 168 mm
	with NAG-D 50 mm 238 mm
	with NAT-D 80 mm 193 mm
	with SAT-D 150 mm 242 mm
Diameter	128 mm

Camera Controller CC31/CC32
Weight without MM30 5.0 kg
L x W x H 300 x 260 x 140
Controls up to five Camera Heads

Camera Controller CC31
Without GNSS/IMU system (for use with Leica ALS)

Camera Controller CC32
With GNSS/IMU system for standalone use

Processor CC31/CC32
Core-I7, Win7 64 Bit, 8 GB RAM, 32 GB CF-card

GNSS/IMU
Supports wide variety of IMUs
Supports GPS/GLONASS
Deeply coupled solution for more efficient data acquisition

Mass Memory MM30
Solid state drive, 600 GB, 1,600 GB
Weight 0.5 kg
Removable, portable

Peripherals

Leica RCD30 Standalone
For installation in Leica PAV80 for RCD
Height 492,5 mm
Diameter 314 mm
Weight 10 kg

Leica RCD30 Oblique
For installation of oblique Trio and Penta Cameras in Leica PAV100 gyro stabilized mount
Pod 37
Height/diameter/weight 533 mm/407 mm/17 kg
Pod 53
Height/diameter/weight 693 mm/407 mm/18 kg

Operator Interface OC60
12.1" screen with 1024 x 768 pixel resolution

Interface Stand IS40
IS40 stand fits RC30 NAV-sight installation

Pilot Interface PD60
6.3" touch screen with 1024 x 768 pixel resolution designed for cockpit mounting

LiDAR SPECIFICATIONS
SR 70 Project

FLIGHT ALTITUDE- 1800ft AGL

CORRIDOR SPECIFICATIONS- 1800ft wide, 137 miles long

DATES OF FLIGHT- Aug 19 – Sep 26, 2018

LIDAR SENSOR- Riegl LMS-Q680i

DENSITY- 8 ppm

HORIZONTAL ACCURACY- .5ft RMSE

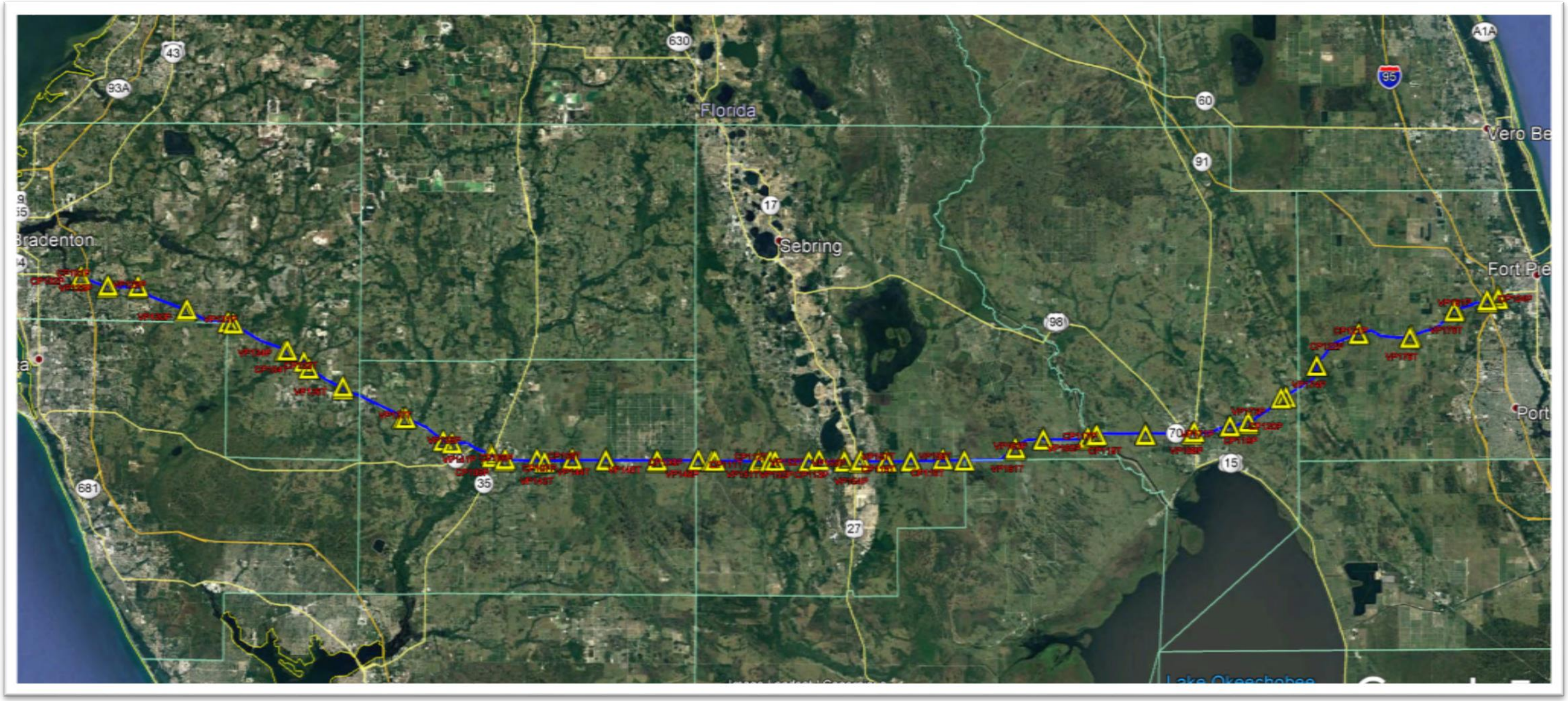
VERTICAL ACCURACY- .25 NVA

DATUM/PROJECTION- NAD83 (2011), UTM Zone 17, US ft

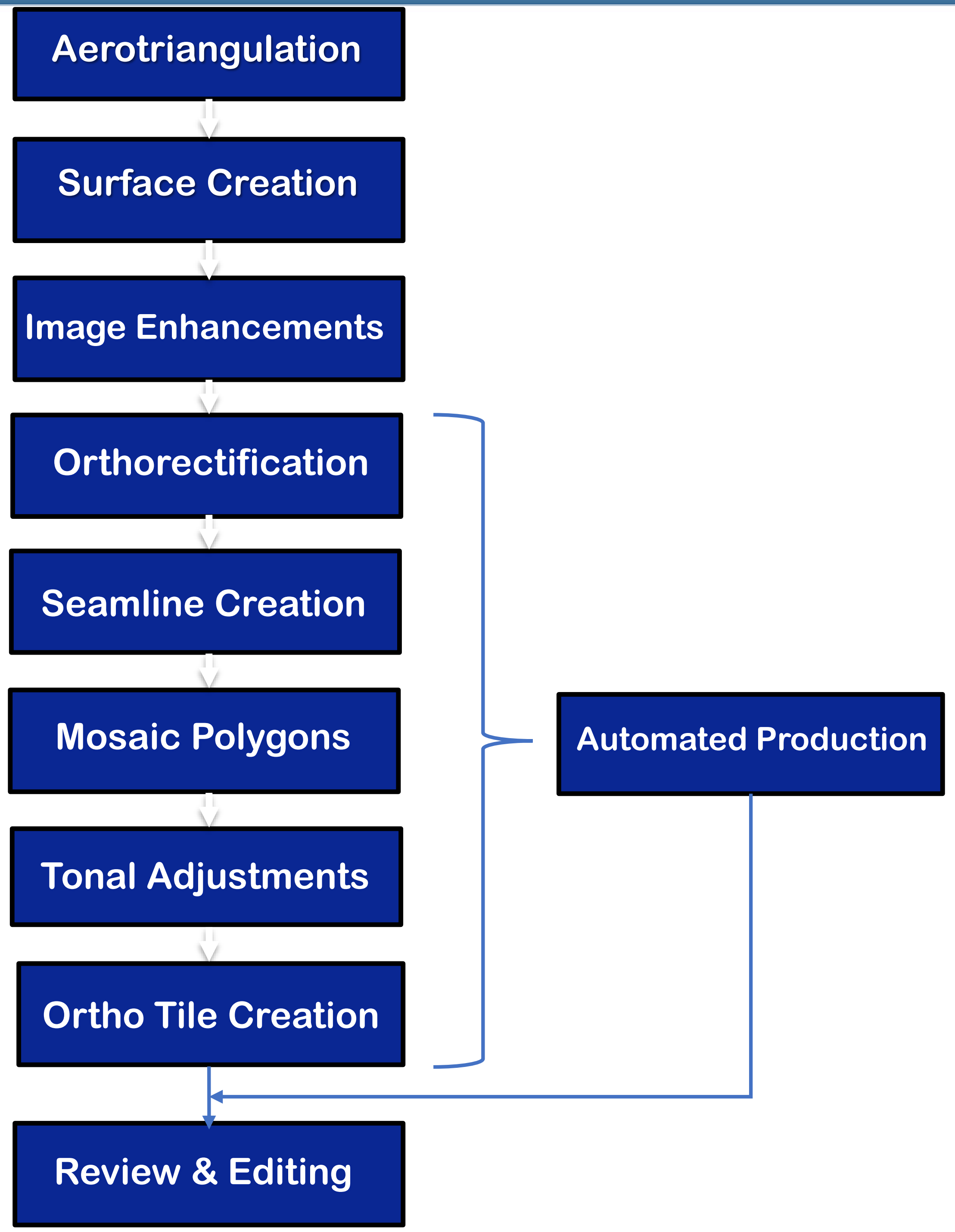
FDOT TRANSPORTATION SYMPOSIUM

CONTROL PLAN SR70 PROJECT

23 Control Points, 59 Validation Points



ORTHOPHOTOGRAPHY WORKFLOW

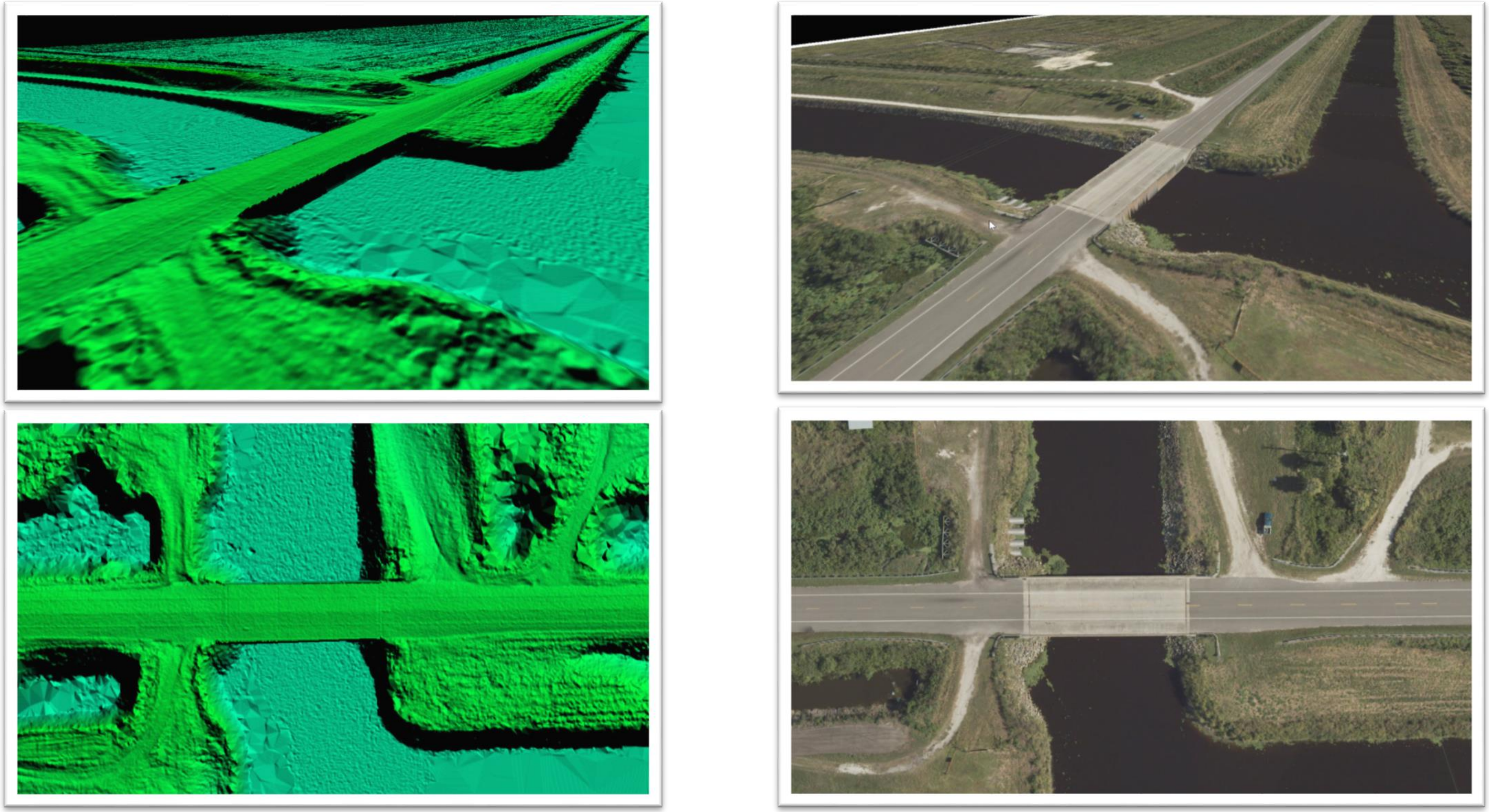


Surface Modeling

- USGS DEM surface tiles were created from LiDAR data ground points provided by consultant.
- DEM files were processed and cut using Global Mapper. Batch conversion created DEM tiles that match LiDAR tiling structure.
- DEM tiles were cut to 2500'x2500' with .50ft grid spacing.
- UTM Zone17N NAD83 2011 US Svy Ft, was used for DEM tile creation.
- DEM generated from LiDAR was reviewed in Global Mapper and bridge areas were identified with polygons.
- Major bridges were integrated into the surface model by adding the bridge decks extracted from LiDAR DSM.
- Where required, Hexagon Imagestation ISAE extended was used to create per-pixel photogrammetric point clouds (.25ft gsd). These point clouds were then integrated into the DSM to be used for orthorectification.
- Minor bridges were outlined with polygons which were used to QC orthorectified imagery.
- Point clouds were edited in bridge areas using Global Mapper

Surface Creation for Orthorectification

USGS DEM from lidar ground points .5ft grid spacing



AT Preparation for Orthorectification

- Aerotriangulation blocks created by consultant were used for orthorectification.
- Consultant AT was processed with Hexagon Imagestation ISAT software
- AT blocks were brought into Hexagon Imagestation ISPM and edited to link to the location of the raw aerial images stored on FDOT network.
- Consultant utilization of correct project specifications was verified in ISPM.
- UTM Zone17N was utilized due to project crossing state plane zones.
- Computed Exterior Orientations for images were verified.

Orthorectification

- Hexagon Imagestation OrthoPro photogrammetric software was used to produce the orthoimagery for this project.
- Image rectification was performed on a Xeon dual processor workstation with 16 core processing capability.
- USGS DEM tiles were loaded into OrthoPro and used as the rectification surface.
- Orthoimages were created for each aerial frame. 3371 total images comprising 70 flightlines
- .25 ft GSD was assigned to output images.
- 4band RGBN tiff format was retained for orthoimage creation. 32bit images (8bit per channel).
- Bilinear interpolation method was used.
- Areas of no coverage in each image tile were designated as intensity value 255

Orthoimagery Creation

- For use in mosaic exporting, an image tiling structure was created by matching the LiDAR tiling format provided by consultant.
- Corridor boundary was created using maximum image extents from aerial imagery. Smooth parallel corridor was used.
- Preliminary full resolution orthomosaic was generated using Hexagon Imagestation Orthopro. Radiometric and color adjustments were not made during this stage.
- OrthoPro automated seamline creation tool was used to generate mosaic seamlines.
- Seamlines and mosaic polygons were exported from OrthoPro for use in quality review and for mosaic editing.
- Preliminary Orthoimage tiles were loaded into Bentley Microstation and a full quality assessment was performed.
- During the orthoimage QAR, imperfections caused during seam-lining, DEM inaccuracies, or color balancing issues were marked for correction.
- Bentley Microstation was used to route seam-lines around elevated features such as buildings, areas of significant color/tone difference, or areas of significant relief
- Areas of distortion caused by excessive relief or poor surface modeling were corrected using Global Mapper to edit the source LiDAR points and photogrammetric point clouds.
- Radiometric and color balancing was addressed by creating a Lookup Table in Hexagon Digital Image Analyst. This LUT was used in subsequent mosaicking processes
- Orthoimage tiles were re-created using edited seamlines. Radiometry and color balance adjustments were introduced
- Compressed image tiles were exported as a batch process in Global Mapper to create uncompressed scanline 4band tiff images.
- Orthoimagery was reviewed again with emphasis on revised areas and tonal adjustments.

QA/QC Process

- Bentley Descartes
- Seamline Review
- Tile Edge Review
- Tonal Issues
- Surface Warping
- Update Surface Changes
- Orthorectification rerun
- Mosaic Process rerun

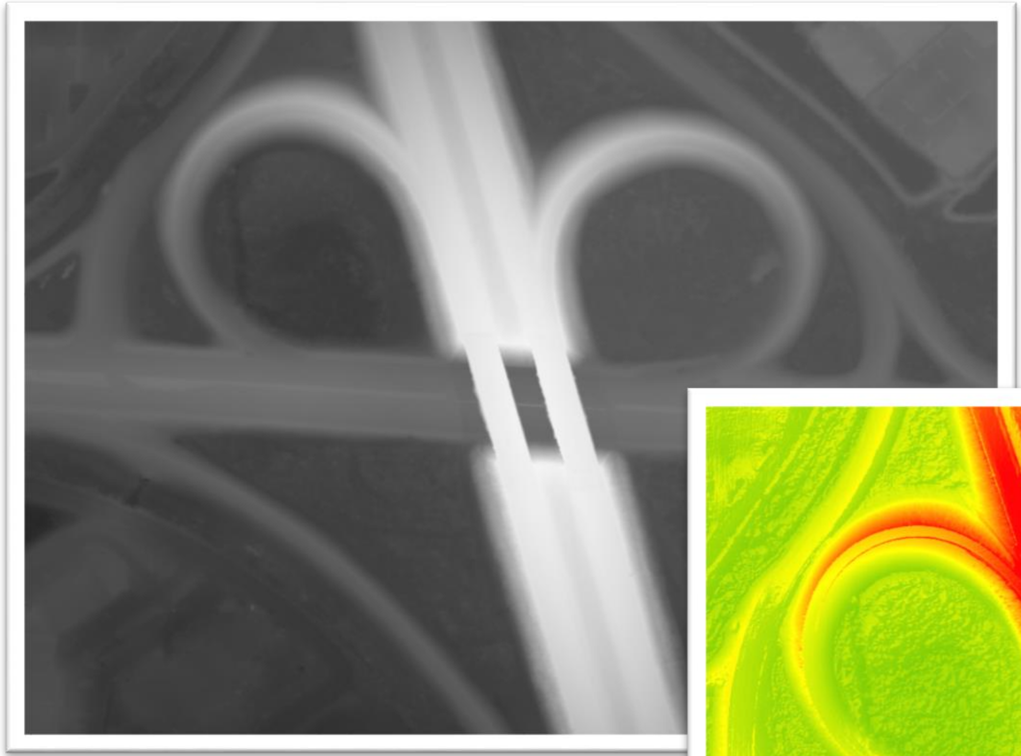
PLATFORMS FOR VIEWING IMAGERY & SURFACES

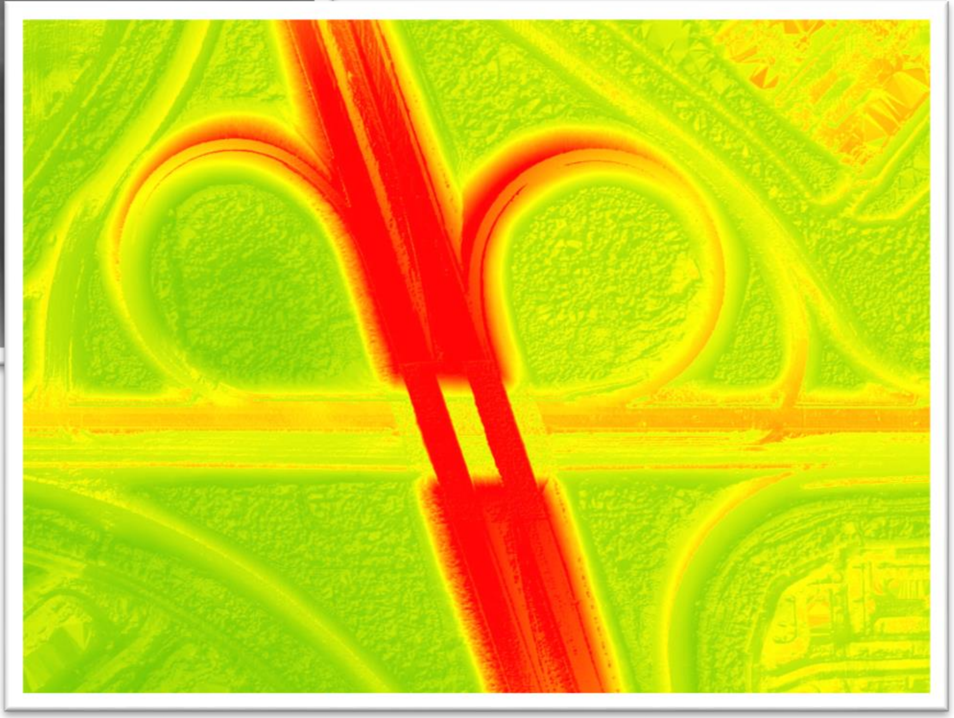
- **Bentley**

  Descartes

  OpenRoads Designer

- **ESRI ArcGIS**
- **AutoCAD Civil 3D**
- **Global Mapper**



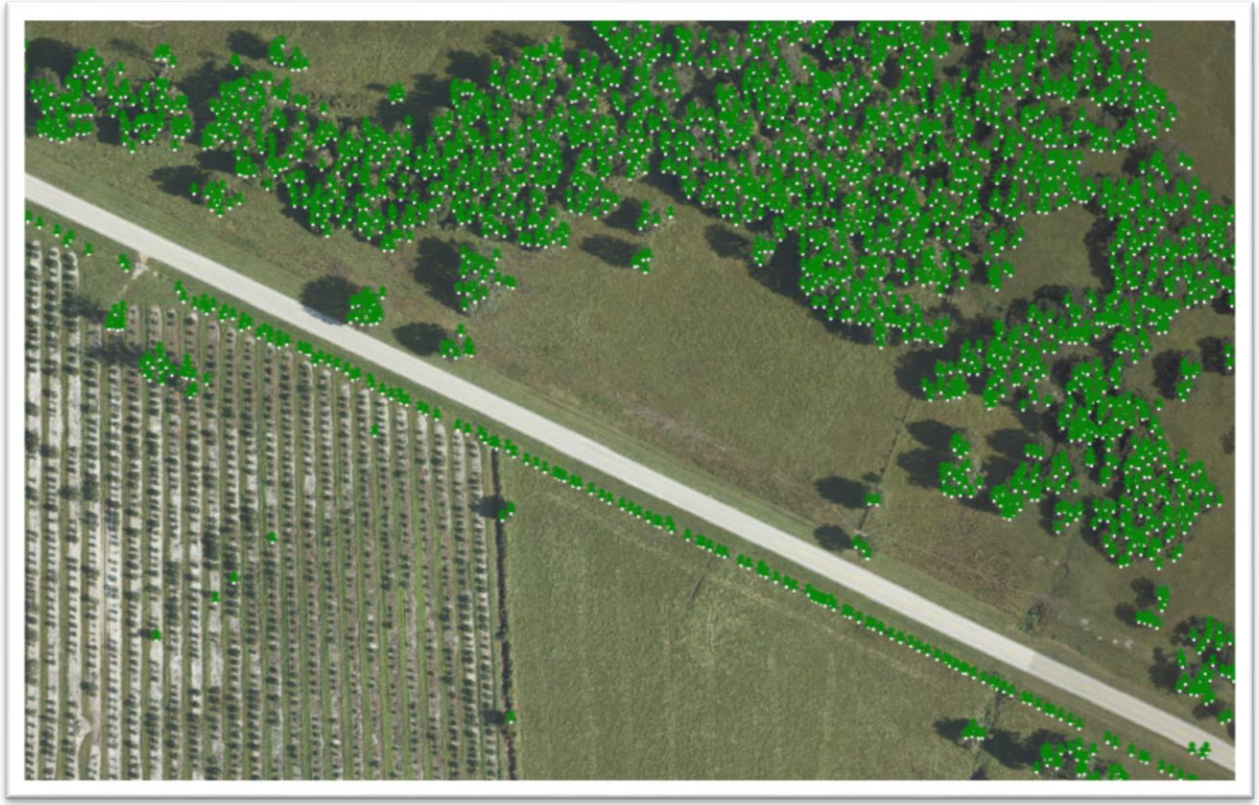


AUTOMATED VEGETATION EXTRACTION

Global Mapper v 20.1 Lidar Module

Source Image/Lidar

Vectorized Vegetation Areas



FDOT TRANSPORTATION SYMPOSIUM

AEROTRIANGULATION USING MULTI-RAY STRUCTURE FROM MOTION

Bentley®

ContextCapture
CONNECT Edition

Project Setup

- 1.25hrs

Control point placement

- 5.50hrs (82 points)

Aerotriangulation Processing

- 3.3 hrs (machine time)

Project:	6820_SR70
Number of photos:	3371
Ground coverage:	5735.716 square kilometers
Average ground resolution:	5.3248 cm/pixel
Scale:	1 : 160
Camera model(s):	Unknown camera model
Processing date:	4/9/2019 12:28 PM
Processing time:	3h 21min

Quality Overview

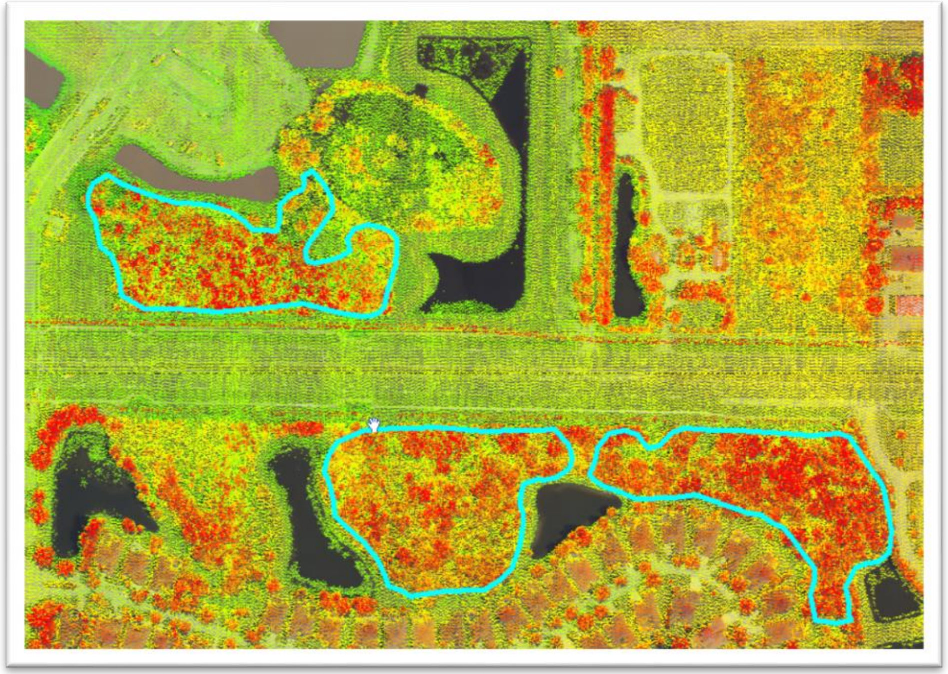
Dataset:	3370 of 3371 photos calibrated (100%)
Keypoints:	Median of 21413 keypoints per image
Tie points:	860560 points, with a median of 1316 points per photo.
Reprojection error (RMS):	0.48 pixels
Positioning / scaling:	Georeferenced using control points

Lidar Vertical Accuracy

Non-Vegetated Areas (NVA)

Performed by FDOT

Total Points	**26**	Sum	1.154
		Average	0.044
		RMSEz	0.211
Accuracyz at 95% Confidence Level		NSSDA	0.4



FDOT TRANSPORTATION SYMPOSIUM

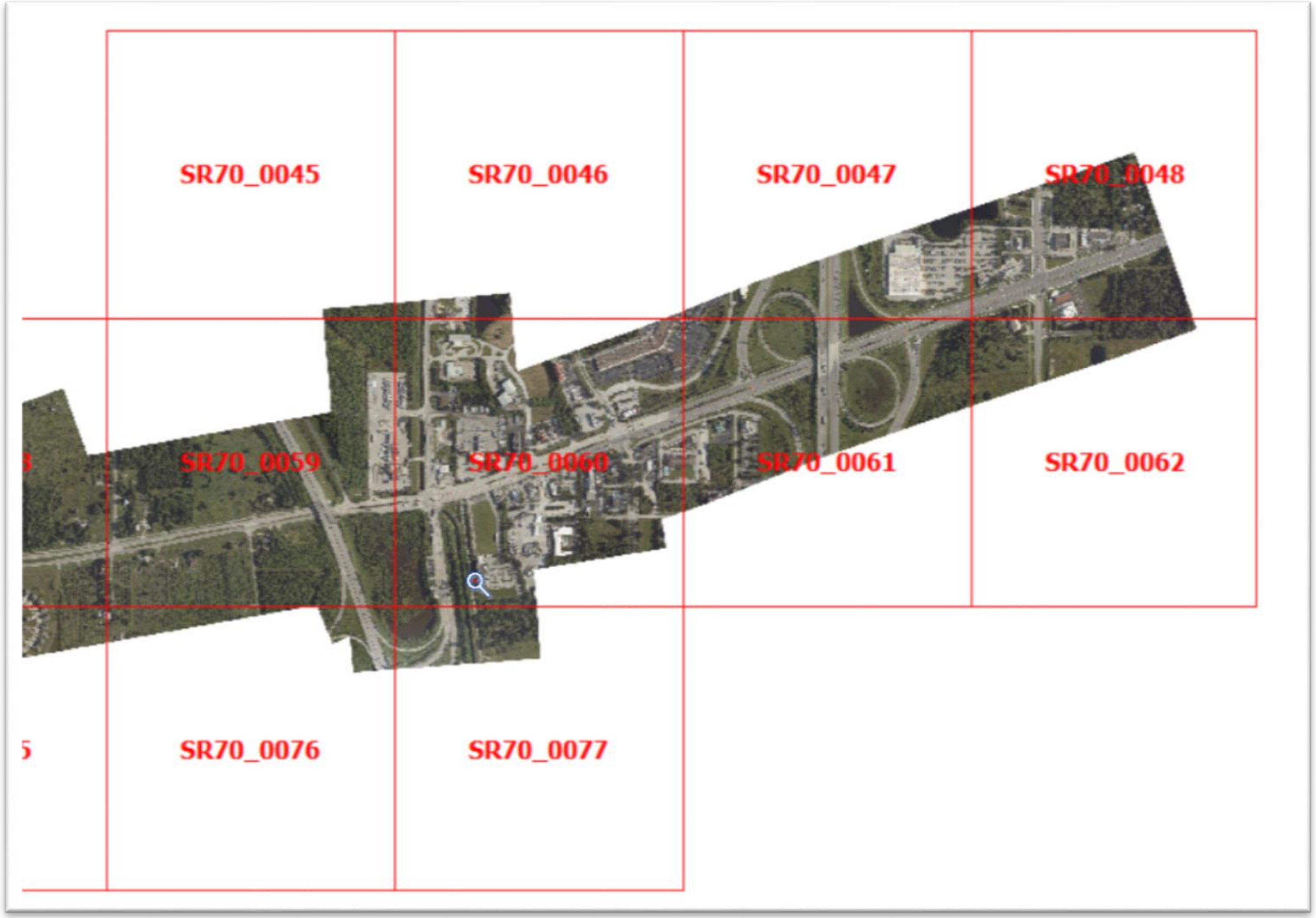
Orthoimagery Availability
SR 70 Project

FORMATS- TIFF, SID - RGBI

TILE SIZE- 2500ft X 2500ft

RESOLUTION- .25ft GSD

DATUM/PROJECTION- NAD83 (2011), UTM Zone 17, US ft



FDOT TRANSPORTATION SYMPOSIUM

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